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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Medical Selection and Physiological Training of Future Fighter Aircrew

NORTH ATLANTIC TREATY ORGANIZATION

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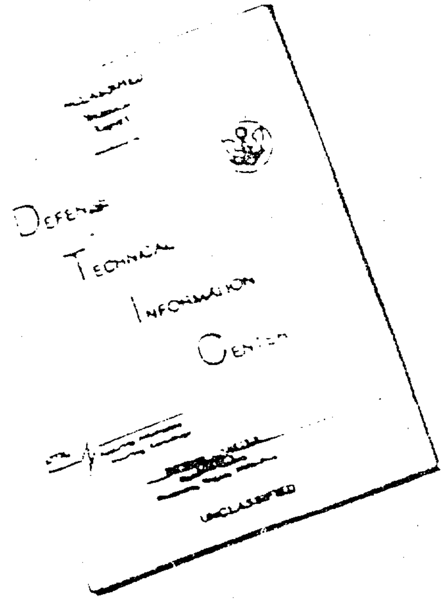

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.396

MEDICAL SELECTION AND PHYSIOLOGICAL TRAINING OF FUTURE FIGHTER AIRCREW

Papers presented at the Aerospace Medical Panel Symposium held in Athens, Greece, 25-26 April 1985.

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PREFACE

Several members of NATO have commenced the development of new fighter aircraft which are to be introduced into operational use in the latter part of the 1990s. These future fighter aircraft will be very agile, capable of sustaining +9 Gz, and will employ very advanced weapons systems. In order to avoid overloading the single pilot there will be extensive use of automatic operation of the aircraft systems, the engines and the weapons. Multi-function coloured displays will be used in the cockpit together with aural warnings and voice operated devices. The pilot will be provided with an excellent external view and, although he will employ helmet mounted displays and sights, he will still be required in some situations to detect, identify and attack targets using his unaided vision. In addition, the aircraft may be operated in a chemical warfare environment when the pilot will be required to wear protective equipment.

The performance of these new fighter aircraft and the manner in which they will be operated requires a very high level of performance from the pilot who will at times be highly stressed both physically and mentally. The pilots selected and trained to operate the future fighter aircraft will require a high standard of medical and perhaps physical fitness. In addition, the physiological training given to these pilots should probably differ from that used at present by many NATO air forces. There was, therefore, a clear need to review the medical selection and physical and physiological training which should be used for this group of pilots. Those air forces which are operating the F-15, F-16 and Mirage 2000 aircraft have already had to amend their medical selection and physiological training procedures. The Aerospace Medical Panel decided, therefore, that it would be appropriate to hold a symposium to review and highlight the medical selection and monitoring procedures which should be used for pilots of future fighter aircraft. The symposium also considered the physiological and physical training which should be provided for future fighter pilots.

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TECHNICAL EVALUATION REPORT

By
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INTRODUCTION

The Aerospace Medical Panel symposium on "Medical Selection and Physiological Training of Future Fighter Aircrew" was held at the Zappeion Exhibition Hall, Athens, Greece on the 25th and 26th April 1985. Authors from five NATO countries presented twenty-three papers.

THEME

The theme of the symposium was the medical selection and physiological training of aircrew who are to operate the high performance fighter aircraft which are to be introduced into service in the 1990s and beyond. The Special Clinical and Physiological Problems in Military Aviation Committee of the Aerospace Medical Panel recognised in 1983 that the high performance fighter aircraft recently introduced into service and under development within NATO, together with the increasing emphasis on the requirement to maintain air operations in the presence of chemical and biological warfare agents, require a very high standard of performance from the aircrew in the face of increasing environmental stresses. The advent of such airacraft which impose more intense and novel aviation stresses and the environment in which they are to operate raised questions with respect to the medical and physical fitness of the aircrew who are to fly them. The Committee also recognised that the advent of these new fighter aircraft required a review of the physiological training which these aircrew should undergo. The Committee recommended to the 40th Business Meeting of the Aerospace Medical Panel, which was held in October 1983, that the Panel should hold a symposium on the medical selection and physiological training of future fighter aircrew. This recommendation was accepted by the Panel and Médicin Géneral Inspecteur J Colin (FR) and Air Commodore J Ernsting (UK) were appointed Session Organisers of the symposium. The call for papers was issued by the AMP Executive in May 1984. A total of twenty-five abstracts were received, of which twenty-one were accepted. Two introductory papers on future fighter aircraft, one from France and the other from the United States, were by invitation. The programme for the symposium was finalised by the Session Organisers early in October 1984.

PURPOSE AND SCOPE

The purpose of the symposium was to discuss those aspects of the medical selection and physiological and physical training of aircrew which were considered to be important with respect to the performance required of aircrew operating new and future fighter aircraft. Areas of medical selecton which are of importance here relate to the high sustained accelerations to which the aircrew may be exposed, the need for very high visual performance in relation to target detection and recognition, and the new forms of visual displays which they will be required to use. Aspects of physiological and physical training which are of importance relate again to the high sustained accelerations and potentially disorientating environment the aircrew will be exposed to in these aircraft and the need for the aircrew to receive detailed, systematic training in how to maintain performance in these environments, and how to use sophisticated visual enhancement devices and the complex personal equipment required to protect against chemical and biological warfare agents.

The major features of the environment of aircrew operating new and future fighter aircraft defined naturally the scope of the symposium. Thus the need to ensure that aircrew are physically fit to operate in the high sustained acceleration environment and to avoid cardiovascular disease led to consideration of cardiovascular selection techniques. This feature of the environment also warranted consideration of the physical stamina and special physiological training necessary to enable aircrew to operate high performance combat aircraft. The continuing emphasis on vision as the primary pathway whereby aircrew receive information concerning their environment and the evolution of new techniques for assessing visual function warranted considerable attention to this special sense. The provision of protection against chemical and biological warfare agents and other hazards such as nuclear flash blindness and the use of visual enhancement devices led to considerations of the physiological training required by these aircrew. The very high agility which will be a feature of future fighter aircraft makes disorientation, which is already a serious problem in aircraft such as the F-16, an even more prominent potential cause of impaired performance and accidents. These considerations led to the need for the methods of physiological training of aircrew to be reviewed during the symposium. The symposium organisers recognised that experienced already gained with new fighter aircraft recently introduced into service such as the F-16, the F-18 and the Mirage 2000, provided a firm basis for the prediction of problems which may arise in future fighter aircraft and the medical selection and physiological training procedures which will be required to avoid and overcome them. Thus papers detailing current experience of the medical selection and physiological training of aircrew for the new generation fighter aircraft such as the Mirage 2000, the F-16, the F-18 and the Tornado were invited and included in the programme.

SYMPOSIUM PROGRAMME

The symposium ~~comprised~~ seven sessions as follows:

(1) ~~The first session~~, Performance of Future Fighter Aircraft, which consisted of two papers describing those features of future fighter aircraft ~~relevant to the subject of the symposium, set the scene for the meeting.~~ such as the Mirage 2000, the F-16, the F-18, and the Tornado.

The second session, Medical Selection : General, comprised two papers which presented an overview of present medical selection procedures with emphasis on those used for fighter aircrew.

The third session, Medical Selection : Cardiovascular Aspects, covered the detection and prediction of cardiovascular disease and the cardiovascular effects of high sustained acceleration. It included a very valuable presentation on the way ahead with respect to these aspects of the selection and retention of the pilots of high performance aircraft.

The fourth session, Medical Selection : Vision Aspects, reviewed important aspects of vision, in particular target acquisition and use of coloured displays, and the vision standards which are required of pilots operating high performance fighter aircraft.

The fifth session, Medical Selection : The Spinal Column, considered the hazards to the neck and the cervical portion of the spinal cord produced by the high acceleration environment and discussed methods of detection and avoidance of cervical vertebral disease.

The sixth session, Medical Selection and Training : Physical Fitness, dealt with the assessment of physical fitness in aircrew and its relation to performance in flight.

The seventh session addressed the physiological training which should be provided to aircrew with emphasis upon those who are to operate high performance combat aircraft.

TECHNICAL EVALUATION

It is convenient and probably useful to present a technical evaluation of each of the seven sessions which comprised the symposium and then to consider the major factors brought out by the symposium in the concluding section of the evaluation.

Session I - Performance of Future Fighter Aircraft

The organisers envisaged the two invited papers which comprised this opening session of the symposium as scene setters. The papers were to highlight those features of the fighter aircraft to be introduced into service in the 1990s and beyond which will determine the environment in which the pilot will be required to operate and the performance required of him. In view of present fighter aircraft development programmes within NATO one paper was invited from the United States and the other from a European country involved in the development of the European Fighter Aircraft (EFA). The US paper (No 28) was contributed by Lieutenant Colonel Krobusek of the USAF Flight Dynamics Laboratory at Wright-Patterson Air Force Base. The "European" paper was contributed by France and the speaker, because of the considerable differences which existed at the time of the symposium between the European air forces engaged in the development of a Staff Target for a European Fighter Aircraft, confined his presentation to a discussion of the French combat aircraft for 1995. Although there are some differences of emphasis in the operational requirements and technical solutions to those requirements between the French Air Force on the one hand and the German, Italian, Spanish and British Air Forces on the other, the overall requirements, and particularly those of aeromedical interest, are very similar. It was possible, therefore, to gain a reasonably balanced picture of those aspects of the performance and the operational roles of fighter aircraft to be introduced into the NATO air forces in the 1990s, which affect the pilot and may be affected by his performance.

The paper (No 27) by Colonel Viant, a member of the French Air Staff, described the new combat aircraft which France intends to introduce into service in 1995. This aircraft is to be highly agile with equal priorities being attached to the air-to-air (air superiority fighter) role and the air-to-ground (ground attack) role. In this respect the French requirement differs from that of the other European NATO air forces involved in the EFA programme. The latter (GE, IT, SP and UK) place primary emphasis on the air-to-air role with the air-to-ground role being a secondary function of the aircraft. In the air-to-air role the aircraft is to be able to intercept and destroy enemy fighters both beyond visual range and in close combat, and to destroy bombers and helicopters. In the air-to-ground role the aircraft is to be able to attack airfields, enemy ground forces and armour and battlefield interdiction targets. The aircraft must operate effectively under all weather conditions both by day and by night and in the electronic warfare environment which is predicted for the 1990s. Although ideally the performance of these very demanding tasks requires a crew of two, all the European air forces involved in the EFA programme have opted for a single seat aircraft for cost reasons. The future fighter aircraft of the USAF is also to have only one crew member. It is argued that advances in cockpit and system design will allow a single crew member to carry out all the tasks demanded of him. There is no doubt that one of the major human factor problems of these new aircraft is the danger of excessive workload for the pilot, a subject which has been considered in another symposium held recently by the Aerospace Medical Panel "Human Factors Considerations in High Performance Aircraft" (AGARD Conference Proceedings 371, 1984).

In order to outclass future enemy fighters the new fighter aircraft (EFA and the USAF aircraft) is required to be lightweight, highly agile, have a high Specific Excess Power, a high sustained turn rate and an airframe capable of sustaining +9 Gz with full weapons and fuel load. It is to be provided with in flight fuelling and to be capable of sorties lasting up to 10 hours. Although it is to be extremely agile, the EFA will be conventional in that the accelerative forces applied in the Y axis will be negligible. It is very likely, however, that the USAF future fighter aircraft will incorporate direct side force and direct lift, the value of which has already been demonstrated in the AFTI/F-16 programme. With this technology the pilot will be exposed to significant transverse accelerations.

The future fighter aircraft is to be equipped with advanced radar and air-to-air missile systems which will permit the simultaneous engagement of several targets both beyond visual range and in close combat conducted under direct vision. Many aircraft and weapons functions which were previously under the direct control of the pilot are to be automated. Thus the engines are to be monitored and controlled automatically as is the performance of many other aircraft systems and system failures are to be dealt with automatically, the pilot being informed of the failure only when it affects the performance of the weapons system. Navigation is also to be automated with automatic terrain following.

The cockpit of the future fighter aircraft is to provide excellent all round vision. It will incorporate the HOTAS (hands on throttle and stick) concept, multifunction displays, and a wide angle HUD (head up display). Colour coding will be incorporated into the displays. In addition, some form of helmet mounted sighting system, probably incorporating limited display of information, will be employed depending upon the weapons system to be used. Night vision goggles and forward looking infra-red sensors will be employed in certain scenarios. Speech will also be used as a means of communication between the pilot and the aircraft systems with voice control using single words.

Both authors recognised the importance of providing adequate protection to the pilot against chemical warfare agents. They concluded that considerable improvements in protective ensembles to reduce the encumbrance which they impose on the pilot are required. The authors also considered the need for improvements in protection against nuclear flash blindness, particularly when considering the use of night vision goggles. There is a need for the development of novel methods of providing protection against this hazard.

The major novel features of physiological and psychological concern associated with the new United States and European Fighter Aircraft as highlighted in the two opening papers and the subsequent discussion were as follows:

(1) The acceleration environment - the new aircraft will be capable of sustaining +9 Gz with very high rates of onset. The pilot, who may well be wearing a helmet mounted sight/display, will require good all round vision even at high +Gz levels. The pilot will be exposed repeatedly during air combat to high G applied very rapidly. Although not to be used in the EFA, a future US fighter will almost certainly apply significant acceleration in the Gy axis. All air forces recognise the disadvantages of a fully reclined seat as a means of improving tolerance of +Gz acceleration. In particular, the loss of panel space within the cockpit and restricted external vision were emphasised in the USAF paper (No 2b). The French Air Force intends to use moderate reclination of the seat (32° angle between seat back and vertical axis) combined with elevation of the lower limbs. The other EFA partners consider that the advantages of a conventional seat back angle outweigh the small increase in +Gz tolerance provided by an angle of 32°. Other methods of enhancing tolerance of +Gz acceleration under consideration are anticipatory inflation of the G trousers and pressure breathing. The transverse accelerations which will be experienced in a future USAF fighter will require, at a minimum, a shoulder pad restraint system.

(2) Interaction between the pilot and the aircraft - the new aircraft will embody the philosophy of full automation of all routine functions with the pilot's effort being devoted to management of tactics and decision making. This change is essential in order to avoid an unacceptable workload on the pilot. Information on the aircraft and weapons systems and that obtained from the aircraft sensors will be presented through multifunction visual display units (VDU), a wide angle HUD and a helmet mounted sight/display. The VDUs will employ colour. Direct vision will be enhanced by the use of night vision goggles. The cockpit design will employ the HOTAS concept and voice actuated controls. Depending upon the outcome of research at present underway, artificial intelligence may be incorporated into the control systems with the aim of further reducing the workload on the pilot. This type of change to the man-machine relationship may well not be very acceptable to present pilots and may well of itself introduce stress.

(3) External vision - in spite of the advanced sensors and displays to be incorporated in the future fighter aircraft, great emphasis is being placed by the Air Staffs on the value of the pilot being able to detect, locate and attack targets using direct vision. Good all round vision is considered to be essential and yet helmet mounted devices are to be used and the crew member will be exposed to high +Gz (and perhaps to ±Gy) accelerations.

(4) Protection against NBC hazards - the pilot will be required to operate in a chemical warfare environment and will almost certainly be encumbered by personal protective equipment. Protection of vision against flash blindness from the detonation of tactical nuclear weapons will also be required in certain scenarios. Provision of protection against flash blindness requires either a helmet mounted device or a cockpit with only a small visual area.

(5) Increased safety - the systems of the new fighter aircraft will have increased redundancy and reliability. Attention is being given to the possibility of providing automatic recovery of a stable flight condition in the event that the pilot loses control due to the effects of high +Gz acceleration or disorientation.

Session II - Medical Selection : General Aspects

The two papers (No 29 and 30) comprising this session dealt with the general aspects of the medical selection of aircrew with emphasis on aircrew who are to operate fighter aircraft. The papers drew on the experience of recent changes in selection procedures in the Canadian Forces (CF) and in the United States Air Force. In the relatively small CF air force there is a policy that all pilots must be capable (medically) of performing all piloting duties, a state of affairs very similar to that which exists in many of the smaller NATO air forces. The USAF has, since 1981, introduced a categorical medical waiver system which allows aircrew who are unfit to fly high performance fighter and attack aircraft to continue to operate, provided that they are fit to do so, tanker, transport and bomber aircraft. In the longer term the USAF is considering introducing special medical selection tests for fighter and attack pilots.

General DeHart's paper (No 30) highlighted the experience of the Tactical Air Command that human factors variables contributed to two-thirds of the losses of USAF fighter and attack aircraft in 1984. Spatial disorientation and G induced loss of consciousness are considered to be the most prominent causes of accidents. The author emphasised the importance of adequate medical selection and of physiological training in reducing the incidence of serious accidents and improving the performance of the fighter pilot. Improvements in selection procedures and stricter criteria of fitness for fighter pilots were established in the USAF in the period 1977-1979 and several of them were adopted in 1981/82. The medical selection procedures for aircrew

in the Canadian Forces have undergone major changes in the last few years. Lieutenant Colonel Gray described the new procedures in his paper (No 29) together with selection procedures which are at present being evaluated by the Canadian Central Medical Board. As with the recent changes in medical selection procedures in the USAF, the procedures adopted by the CF are aimed at improving the ability of pilots to operate high performance fighter aircraft.

Both the USAF and the CF have instituted procedures designed to reduce the incidence of coronary artery disease in aircrew. Major cardiovascular risk factors are determined although, as pointed out by Colonel Hickman in the discussion of these papers, the only factors likely to be of value in young men are the blood lipid concentrations. Echocardiography has recently been introduced as the most valuable non-invasive tool for detecting structural cardiac abnormalities in clinically normal individuals. The USAF is employing this technique routinely in the selection of fighter pilots whilst the CF are commencing a clinical trial to study its value as a screening tool for pilot candidates.

The need for fighter pilots to have a very high standard of vision has led to revision of visual standards and the search for improved methods of measuring visual performance. Until 1982 the USAF operated a waiver policy for reduced visual acuity, candidates with 20/50 VA being accepted routinely for pilot training. In 1980, 38% of graduate officers undergoing pilot training wore corrective flying spectacles. Since 1982, all pilot candidates in the USAF have been required to have 20/20 VA. Both the USAF and the CF are investigating the value of determining contrast sensitivity using sine wave gratings. The Canadian Central Medical Board has already found the technique to be of value in discovering undetected ocular disease. The value of measurement of contrast sensitivity was explored more fully in Session IV of the symposium.

The USAF has also considered the introduction of additional medical selection procedures for fighter pilots related to the high +Gz levels to which they are exposed. In addition to the cardiovascular system attention was directed to the musculo-skeletal system - particularly the cervical spine and the neck muscles. The latter reflects the increasing incidence of moderate and severe neck conditions occurring in fighter pilots. The USAF is considering, but has not yet adopted, routine radiography of the cervical spine in the selection of these pilots. Colonel Hickman, in the discussion, highlighted the ethical problem which arises in applying a selection procedure which has an element risk to a population, a significant proportion of which will never be exposed to the hazard for which the selection procedure is introduced. He highlighted the advantages of a dual track pilot training system where it is possible to limit the use of medical procedures which have an element of risk to those pilots who have been selected for flying in which the hazard exists. The CF have also introduced pulmonary function testing of all aircrew candidates aimed at detecting early disease of the small airways on the premise that the stability of the small airways may affect a pilot's tolerance of sustained +Gz acceleration. The evidence to support the addition of this form of test is not strong although many air forces employ tests of lung function in candidates with a history of asthma.

Session III - Medical Selection : Cardiovascular Aspects

This session, which was devoted to the cardiovascular system, comprised four papers, one (No 31) from the USAF School of Aerospace Medicine which presented one philosophy for this aspect of the selection and retention of fighter pilots and three papers (No 32, 33 and 34) from the French Air Force on specific aspects of the subject.

The USAF paper (No 31) by Colonel Hickman and his colleagues gave an excellent perspective of the philosophies on cardiovascular selection and their application in the USAF. The unrivalled collection of clinical data on aircrew which has been built up by the USAF School of Aerospace Medicine over the last 30 years or so provided the basis for the development of philosophies presented in this paper. The authors present a well argued case for their view that cardiovascular selection procedures for the young fighter pilot should be based upon the resting electrocardiogram (both ambulatory and treadmill testing give rise to a large number of false positive findings), the echocardiogram to detect common structural defects of the heart and coronary artery disease risk factor analysis (including family history, hypertension and blood lipids). The authors also consider the point in flying training at which specialised selection procedures for the fighter pilot such as echocardiography should be carried out. They suggest, in a large air force such as the USAF which can afford to have a dual track system in which pilots are selected after completion of basic flying training for advanced training as either fighter/attack/reconnaissance pilots or tanker/transport/bomber pilots, specialised medical selection procedures should be employed after the individual has been selected for training as a fighter/attack pilot. The economic and retention of aircrew advantages of this approach are considerable. They point out that the dominant form of cardiovascular disease which may occur in fighter pilots once they have been selected in this manner is silent coronary artery disease, and advocate recurring risk factor analysis in this group. Invasive studies to determine whether an individual with a clinical or electrocardiographic abnormality can fly should be restricted to fully trained aircrew. Furthermore, invasive studies which carry an element of risk should only be used when this is indicated by risk factor analysis. Colonel Hickman and his colleagues estimate that medical selection for fighter/attack pilot training at the advanced flying training stage will eliminate 5% of aircrew of whom 80% will be fit for training in the tanker/transport/bomber roles. This approach to the medical selection and retention of fighter pilots is extremely attractive and many smaller air forces could well adopt it, albeit in a modified form.

Médicin en Chef Ille and his colleagues of the French Air Force reported (Paper No 32) the initial results of a study using echocardiography in a group of thirty-two fighter pilots and a control group of pilots operating transport aircraft. The two groups of pilots were well matched for age, weight and body dimensions. The authors did not, however, have information on the smoking habits, physical activity and physical fitness of the pilots. Echocardiography revealed borderline abnormalities in eleven of the thirty-two fighter pilots and unsuspected tricuspid insufficiency in a twelfth fighter pilot. Four fighter pilots had slight "ballooning" of the mitral valve into the left atrium, whilst eight had a significant increase in the size of the right ventricle. Four abnormal echocardiograms were found in the control group. Three control pilots exhibited "ballooning" of the mitral valve whilst the fourth, who had served as a fighter pilot in the past, had dilatation of the right ventricle. The increase in the dimensions of the right ventricle in the fighter pilots was highly significant. The authors suggest that it may indicate either an adaptation to the high G environment or early myocardial disease. As was brought out in the discussion, the changes in the right ventricle found in the fighter pilots

could possibly be due to the greater physical fitness of this group as compared with the controls. The changes, with the exception of the case of tricuspid insufficiency, were not considered to be such as to preclude a continuing career as a fighter pilot. The study provided very good evidence of the potential value of echocardiography and the authors strongly supported the USAF view that this technique should be used in the selection and monitoring of fighter pilots. Dr Ille and his colleagues are to continue a longitudinal study of these pilots. The results of the continuation of these echocardiographic studies will be of great interest to the aeromedical community. In the subsequent discussion of the value of echocardiography longitudinal studies of pilots exposed to high levels of +Gz acceleration Colonel Hickman advocated that the AGARD Aerospace Medical Panel should initiate an extensive study of this subject involving the NATO air forces so that a large pool of information on the possible cardiac effects of repeated exposures to +Gz can be collected in a systematic and controlled manner.

The incidence of cardiac arrhythmias as recorded by electrocardiography during exposure to +Gz acceleration was reported in a paper (No 34) from the French Aerospace Medical Laboratory at Bretigny. Dr Clere and his colleagues had examined three hundred and twenty-eight ECGs recorded from one hundred and forty-six subjects before, during and after exposure to plateau +Gz acceleration lasting 20-60 seconds at levels from 4 to 11 G. They were particulary interested in the incidence and nature of arrhythmias during the recovery phase after the exposure to +Gz, drawing similarities between the state of the cardiovascular system in this situation with that on the cessation of physical exercise. The authors found a high incidence of arrhythmias (59% of traces), virtually all of which (94%) were supraventricular. The majority of the latter were sinus arrhythmia or sinus bradycardia which occurred during the recovery phase. None of the ECG changes was associated with any change in the visual fields or level of consciousness of the subjects and the occurrences of symptoms or signs of inadequate cerebral perfusion under +Gz were not related to abnormalities in the ECG. These authors did not see and did not discuss the occurrence of vasovagal syncope on exposure to prolonged +Gz. They concluded that the occurrence of arrhythmias was of no value in predicting an individual's tolerance of sustained +Gz acceleration.

A very interesting study in which the ECG was recorded in flight on a total of thirty-one pilots was reported by Méd en Chef Seigneuric and Méd en Chef Leguay (Paper No 33). These authors employed the standard clinical Holter method to record continuous ECGs over a 24 hour period from seven pilots operating Mirage 2000 aircraft (total 10 flight hours) and a group of twenty-four pilots flying Mirage 3 and F1 aircraft (total 39 flight hours). Average peak +Gz acceleration in the Mirage 2000 was 6.6 G (maximum 8.5 G) and 4.7 G (maximum 6.5 G) in the flights in the Mirage 3 and F1. Very few abnormal beats were seen in the ECGs of either group. The striking finding was the relatively low heart rates recorded during +Gz in flight (85-150 beats per min) as compared with similar exposures in the human centrifuge. Even the exposure to a peak acceleration of 8.5 G in the Mirage 2000 only raised the heart rate to 105 beats per min. The average and maximum heart rates were considerably lower in the Mirage 2000 pilots than in those operating the Mirage 3/F1 who were younger and who had had considerably less flight experience.

Session IV - Medical Selection : Vision Aspects

The importance of a high standard of vision in the fighter pilot to enable him to detect, identify and attack targets in adverse as well as favourable environmental conditions and to use complex optical and electro-optical devices was clearly stated in the presentations on the future fighter aircraft. The session devoted specifically to the vision aspects of medical selection comprised five papers. One of these examined all aspects of vision and proposed entry standards for future fighter aircrew, whilst the other four addressed specific areas of importance - colour vision and dynamic acuity.

The opening paper of the session (No 35) by Dr Brennan comprised a comprehensive and well argued view of the visual standards which should be set for pilots (and navigators) who are to operate fighter aircraft. The emphasis in this paper was on the conventional methods of assessment of visual performance. Pointers to areas where new techniques of measurement may be of value were, however, also considered. Dr Brennan presented the very strong case for imposing high entry standards so as to reduce to a minimum the proportion of aircrew under the age of 45 years who have to wear corrective lenses in flight. It can be argued that in an ideal world the standards should be such that no aircrew less than 45 years old, particularly those operating fighter aircraft, should require visual correction. Many air forces faced with shortages of suitable candidates for flying training have not, however, insisted on these high standards. Although over the last 10-15 years contact lenses have been advocated as the ideal means of correcting visual deficiencies in aviators, trials conducted in the Royal Air Force have shown that this is not so in the military environment. Dr Brennan proposed that candidates with any degree of myopia at all should not be selected for training to fly future fighter aircraft. Colonel Price referred to a study conducted in the United States Army which confirmed that rejecting all candidates with any degree of myopia would reduce the proportion requiring visual correction for the flight task to about 1%. In the area of specialised examination techniques Dr Brennan advocated the measurement of stereopsis and improvements in the methods of testing colour vision and of determining the ability of candidates to detect low contrast targets. Although the author was not strongly in favour of the measurement of contrast sensitivity using sine wave gratings, other members of the symposium were of the opinion that this technique has considerable promise. The outcome of the assessments of this method now being conducted by the Canadian Forces (Paper No 29) and the United States Air Force are awaited with great interest.

Colour vision has always been recognised as of importance to the aviator. The development of coloured cathode ray tube (CRT) displays for use in aircraft led Médecin en Chef Santucci and his colleagues to investigate improvements in the methods of determining colour vision. This group, working at the French Centre for Aerospace Medical Research (CERMA) in Paris, reported in their paper (No 36) the measurement of colour contrast sensitivity. They employed a coloured CRT to display contrast gratings in red, green and blue. Gratings were displayed to the subject for 2 second periods at six spatial frequencies and the subject was required solely to indicate whether or not he saw the grating. The complete measurement (six spatial frequencies in three colours) could be completed for one eye in 15 minutes. Myopia, as might be expected, reduced the contrast sensitivity for the colour blue at the higher frequencies and this attenuation was abolished by correcting the myopia. The CERMA group are continuing this study to determine the limits of normality and the value of the technique as a selection tool. It is likely that such a test, particularly if the time the subject takes to respond to the visual presentation is also measured, has considerable relevance to

the visual task of the pilot of a future fighter aircraft.

Static tests of vision, which is essentially a dyanmic process, have significant limitations. Dr Wolfe and his colleagues at the USAF School of Aerospace Medicine reported (Paper No 37) the use of three tests of the ability of individuals to acquire and track targets. These tests aim to measure quantitatively oculomotor-vestibular function as revealed by electro-oculographic recordings of eye movements during the tracking of a moving target, and during sinusoidal movements of the body (imposed by a turntable on which the subject is seated) and by recordings of saccadic eye movements by an infra-red reflectance technique during tracking of a target moving in discrete jumps. The authors concluded that it is now possible to describe quantitatively both the visual and vestibular control of oculomotor function. There is no doubt that such tests are of value in monitoring in the individual the effects, for example, of repeated exposures to high +Gz upon vestibular function. Their place in selection is more problematical as there have been no formal studies relating performance at target detection and tracking in flight to these measurements of oculomotor function.

An impressive attempt to obtain useful correlations between laboratory tests of visual performance and the air-to-air target performance of aircrew in flight is being conducted by the Naval Aerospace Medical Laboratory at Pensacola. Commander Monaco presented two papers (No 38 and 39) describing this programme. A battery of vision tests which measure central spot detection, central acuity at high and low contrast with and without glare, speed of accommodation (far to near) and detection of lateral movement of a target were used. Mean stimulus threshold together with, in some tests, the mean threshold-stressed response time (the response time to a target which the subject could "just see" correctly) were determined. A sophisticated computerised telemetry system at the Tactical Air Combat Training System range provided extensive data on the flight and engineering status of observer and target aircraft during practice Air Combat Manoeuvres (ACM). The authors employed the direct distance between the two aircraft at the instant at which the pilot initially detected the target aircraft (slant range) as the measure of his air-to-air target performance. One study investigated the performance of ninety-one pilots performing ACM in F-5, A-4 and F-14 aircraft. It was found, as would be expected, that environmental and aircraft conditions such as sun position, cloud, speed and direction of flight, and target size had a greater effect on slant range than the standard of vision of the individual pilot. Significant positive correlations were, however, established between slant range performance and the vision tests, particularly the threshold stressed response times obtained from tests of acuity at low and high contrast, and with glare. This study and that reported in the subsequent paper (No 39) showed that in general, time to respond to a target which he could just see (threshold-stressed response time) was a better predictor of visual performance in the air (slant range) than the stimulus threshold. The authors advocated further investigation of the value of the response time to a target just above the threshold in predicting visual peformance in flight. These papers from the Naval Aerospace Medical Research Laboratory well illustrate the great difficulties which surround assessment of visual performance in flight. There is no doubt, however, that such validation of tests of visual performance must be conducted if improvements are to be made in the selection and monitoring of this important determinant of pilot performance.

Session V - Medical Selection : The Spinal Column

Experience with the F-16 and other aircraft such as the RAF Hawk has emphasised the effects of high +Gz upon the neck muscles and the cervical spine. Two papers (No 40 and 41) were presented on medical selection and monitoring procedures related to the spinal column. Only a limited number of the NATO air forces at present carry out routine radiography of the spine in the initial medical selection of aircrew. The French Air Force does, however, perform radiography of the complete spine (eight radiographs) to exclude tumours etc and certain congenital and acquired defects of the spine. The paper from the French Air Force (No 40) reviewed their present standards and concluded that no change in them was required. The other paper (No 41) in this session reviewed the experience of the Royal Netherlands Air Force which introduced spinal radiography in 1982. Major van Dalen emphasised the value of image intensification in this screening process as it reduces the radiation exposure to the candidate to 10% to 25% of that produced by conventional radiography. Of two hundred and twenty-five candidate student pilots examined since 1982, the Royal Netherlands Air Force has rejected 20% for spinal, mainly vertebral osteochondritis and spondylolysis/lysthesis, visualised by radiography. Over the same period half of one hundred and ninety-six qualified fighter pilots were found to have spinal disorders on radiography: 50% of these disorders were in the cervical spine; eighteen pilots had cervical disc disease with osteophytes. A very pragmatic approach was applied to these findings in qualified fighter pilots. Only four pilots were rejected for flying in the F-16 - all of these had cervical disc disease with osteophytes and a further three received a G restriction. All these pilots are to be examined radiologically once a year. The major concern is that cervical disc disease and, more importantly, osteophytes may compress or damage the spinal cord in the cervical vertebral canal. This is obviously an area of considerable concern, although the correct selection criteria have yet to be established. The importance of the strength of the spinal muscles and especially those of the neck to the prevention of injury to the spine was emphasised by the speakers.

Session VI - Medical Selection and Training : Physical Fitness

The relationship between physical fitness and performance of the flight task in military aircraft has been a matter of debate for many years. The advent of aircraft such as the F-16 in which the pilot is repeatedly exposed to sustained high +Gz with the attendent need to maintain posture, to tense muscles to support the cardiovascular system and to perform respiratory straining manoeuvres has rekindled interest in this relationship. Well designed studies conducted at the USAF School of Aerospace Medicine and confirmed by experiments carried out at the Karolinska Institute have shown that gains in muscle strength and endurance produced by moderate resistance training increases tolerance of a standard Air Combat Manoeuvre (ACM), whilst aerobic training does not. This session of the symposium contained two papers which addressed the value of physical training. Médicin en Chef Poyot and his colleagues reported (Paper No 42) a study in which the G tolerance of a group of nine Mirage 2000 pilots was determined on a human centrifuge before and after a six month programme of resistance exercises (limb and trunk muscles) combined with moderate exercise. The mean acceleration tolerance as determined by the GOR technique (0.1 G per second) which was already high (8.7 G) was increased by 1.33 G following the six month period of physical training. The authors pointed out that, in the absence of familiarisation runs on the centrifuge and a control group, it was uncertain whether the improved tolerance could be ascribed to the physical training programme. This study is to be repeated and extended.

An ambitious attempt to relate performance in flight and at flight related tasks to cardiovascular fitness was presented by Lieutenant Commander Banta and Dr Grissett (Paper No 44). The authors sought, in three studies using groups of student and qualified aircrew, correlations between a number of measures of cardiovascular function during maximal exercise on a treadmill and susceptibility to motion sickness, laboratory measures of vision and the heart rate during Air Combat Manoeuvres (ACM) in flight. Maximum oxygen consumption measured using the Bruce protocol showed both the student and the qualified aircrew to have a high aerobic capacity. An inverse relationship was found between aerobic capacity and susceptibility to motion sickness induced by body rotation combined with head movement. The authors suggested that this relationship was probably due to conditioning to the motion associated with physical training. Dynamic visual activity was also found to correlate with aerobic capacity. There was also an inverse relationship between the heart rate at a given phase of flight and aerobic capacity. Although significant correlations were found in these studies it has yet to be demonstrated that an increase in physical fitness will produce an improvement in the performance of pilots in flight. A carefully designed longitudinal study with appropriate controls is required to determine the value of physical training and fitness in this context.

Session VII - Physiological Training

Aircrew must have a general understanding of the physiological effects of the stresses to which they may be exposed in flight and they must be taught how their ability to perform their flight tasks, both in normal and emergency situations, can be affected by these effects. Thus all NATO air forces have training schemes whereby aircrew are taught the relevant aspects of aviation physiology and psychology and given practical experience of the effects of the major aviation stresses. Although instruction in the two subjects may be separated, in practice, training in the purpose, mode of operation and use of life support, escape and survival equipment is closely related to physiological training. In some air forces the tuition of aircrew in aviation physiology and psychology is conducted together with the issue, fit and instruction in the use of life support equipment. The advantages of this approach are considerable.

Three of the papers presented in this session of the symposium (No 45, 46 and 49) described in some detail the philosophies, practice and experience of the aviation medicine training of aircrew in the Royal Air Force. Particular features of the training conducted by the RAF is that it integrates together tuition in aviation physiology and psychology, life support equipment and aircrew NBC protective equipment and procedures, that it is centralised at one major training centre, that the training is aircraft type/role specific and that it is integrated into the flying career of the individual aircrew. This group of papers also emphasised that to be successful an aviation medicine programme must be dynamic, the tuition being modified to match the operational needs of the air force. The development and introduction of improved methods of instructing aircrew in orientation and disorientation in flight described in paper No 45 well illustrates this important aspect of modern aviation medicine training. Another example is evolution of training in use of aircrew NBC protective equipment and procedures in the RAF which was well presented in the paper (No 49) by Dr Macmillan.

The principle that physiological and aviation medicine training procedures should present minimal hazard to the aircrew being trained and to the trainers was the basis of the paper (No 47) on the use of hypobaric chambers by Commander Herron of the Naval Aerospace Medical Institute, Pensacola. He was concerned with the occurrence of decompression sickness in both trainees and trainers associated with exposure to reduced environmental pressure in hypobaric chambers. The incidences of decompression sickness reported in some 59,000 individual exposures over the period 1981-84 were 0.066% of student exposures and 0.285% of inside observer exposures. Commander Herron suggested that this incidence of decompression sickness should lead to the abandonment of hypobaric chamber training for aircrew. He advocated the administration of 7.4% oxygen in nitrogen at ground level as an alternative means of providing students with personal experience of hypoxia. Several speakers expressed surprise at the high incidence of decompression sickness during hypobaric chamber training reported by this author. The incidence of significant decompression sickness during hypobaric chamber training conducted by many other air forces is much lower than that reported in this paper. Discussion suggested that a significant proportion of the incidents might well not be decompression sickness. Unfortunately, the author was unable to give an analysis of the forms of decompression sickness which made up the reported incidents. Personal experience of hypoxia can be given satisfactorily at ground level by the administration of a gas mixture containing a low concentration of oxygen. However, production of hypoxia by breathing air at reduced environmental pressure which more closely simulates the situation for which hypoxia trianing is provided, together with experience of the effects of exposure to low pressure and tuition in procedures such as the Frenzel and Valsalva manoeuvres, leads to the conclusion that hypobaric chamber training should not be abandoned. It may be an appropriate time to carry out a survey of the incidence of decompression sickness (including symptoms and signs exhibited by each individual case) in hypobaric chamber training. Views on the value and acceptability of pre-oxygenation of inside chamber attendants could also be obtained.

The remaining paper in this session (No 48) dealt with one of the most recent and important innovations in the physiological training of aircrew - the use of the human centrifuge to train fighter aircrew in the protective manoeuvres to be used to enhance their tolerance of sustained +Gz acceleration. The approach and training techniques pioneered by the USAF School of Aerospace Medicine had been adopted, with minor changes, by the Dutch authors. Colonel van den Biggelaar described the human centrifuge facility at Soesterberg and the training procedures employed for RNLAF and USAFE pilots operating F-15 and F-16 aircraft (these techniques are also described in AGARD Conference Proceedings 377, 1985). The paper reported the results of the high G centrifuge training provided to forty-six F-15 and one hundred and twenty F-16 pilots during the period 1 April 1984 to 1 April 1985. It was found that on the first centrifuge run 70% of these pilots did not carry out the straining manoeuvre correctly. Only nine of the pilots failed to achieve the goals set for the training programmes; the majority because of motion sickness induced by the relatively short arm of the centrifuge. There is little doubt that the use of the human centrifuge as a training aid combined with appropriate classroom instruction can significantly enhance the ability of pilots to withstand the rapid onset, high sustained +Gz accelerations which are a feature of combat manoeuvres in the F-15 and F-16 and will be of any future fighter aircraft. As described in General DeHart's paper (No 30), the United States Air Force has decided to carry out centrifuge training of all pilots on entry to fighter pilot training. Questions are now being raised as to the frequency with which centrifuge training should be repeated. Experience of the retention by the whole population of other information imparted by practical procedures in physiological

training would suggest that refresher training in the human centrifuge should be repeated once every 2-3 years. The advent of future fighter aircraft with the performance discussed in the opening session of this symposium could well require the provision of centrifuge training for fighter pilots in a way analogous to the introduction of hypobaric chamber training some 50 years ago.

Conclusion and Recommendations

The symposium identified the major features of the fighter aircraft to be introduced into service during the 1990s which will impact on the medical selection of, and physiological training to be given to, the pilots who are to operate these aircraft. These features include all weather, night and day capability, extreme manoeuvreability with rapid onset, high sustained +Gz acceleration (and perhaps ±Gy), potential for increased workload alleviated by extensive automation of aircraft and weapons systems, use of helmet mounted sights, displays and vision enhancement devices, use of colour in cockpit displays, and the need for protection against chemical warfare agents and nuclear flash blindness. In parallel with the development and introduction of medical standards and methods of assessment which will ensure that pilots with the appropriate capabilities will be selected, there is an increasing awareness of the need to exclude those individuals who have a significant likelihood of sudden incapacitation due, for example, to a cardiac infarction. There is also the need for medical monitoring of pilots operating high performance fighters such as the F-15, F-16 and Mirage 2000 as well as future fighter aircraft in order to ensure that the stresses to which they are exposed in flight do not produce disease or aggravate existing diseases.

It is most important that the assessment procedures and standards employed in the medical selection and monitoring processes are well validated. Error in the initial medical selection process may well eliminate individuals who are in fact fit to become fighter pilots, a situation which many air forces can ill afford. Alternatively, poor selection procedures and standards may well allow the entry and retention of aircrew who are not fully fit to perform in the high stress environment associated with modern and future fighter aircraft. The symposium included several examples of the difficulties of validating medical selection and assessment procedures, not least of which is the quantification of the individual pilot's performance in flight. The use of the facilities of modern ACM training ranges, such as those of the USN and USAF, in measuring performance of the fighter pilot's ta[illegible] the validation of medical assessment procedures should, it is suggested, be extended. The value of [illegible] assessment of clinical conditions in aircrew together with meticulous follow up and documentation [illegible] reference is very well illustrated by the work of the Clinical Sciences Division of the USA[illegible]erospace Medicine. This group have an unrivalled bank of data on which to base advice an[illegible]n respec[illegible] to the acceptability or otherwise of a large range of diseases in the aircrew popu[illegible]e example s[illegible] by the USAF School of Aerospace Medicine should be emulated by the medical organisations of other NATO air forces.

The high G environment to which pilots of present and future fighter aircraft will be exposed is one of the two major factors influencing medical selection procedures. This feature of the aircraft demands special attention to the cardiovascular and musculo-skeletal systems. The medical selection and monitoring procedures related to reducing the risk of coronary artery disease to a minimum must be applied vigorously to the pilots operating fighter aircraft. In addition, special procedures are required to eliminate cardiovascular conditions which may impair the ability of the pilot to perform well in a high G environment and those which may be aggravated by repeated exposure to high G. There is no doubt that echocardiography has a vital part to play in both the routine selection and monitoring of fighter pilots. Evidence is accumulatir[illegible] that stress testing on a treadmill and Holter monitoring of the ECG have little or no place in these processes. Well controlled longitudinal studies of fighter pilots using modern, non invasive techniques, particularly echocardiography, should be established wherever they are required to operate at high G levels in order to determine whether this environment has a deleterious effect upon the cardiovascular system, especially the right ventricle. It is suggested that the NATO air forces should establish collaborative studies in this area.

The high G environment places considerable stress upon the spinal column, particularly the cervical spine. The loads placed upon the necks of the pilots of future fighter aircraft will also be increased by the sights and displays and vision enhancement devices such as night vision goggles which will be mounted on the aircrew helmet. Whilst clinical examination provides an adequate assessment of the range of movement of the spine and the strength of the associated muscle groups, significant pathology may be present in the bones and intervertebral discs in the absence of symptoms and signs. Concern with the risks of high G exposures aggravating bone and disc disease which is already present and the possibility, albeit remote, of damage to the spinal cord is leading to the use of radiography of the spine in medical selection and monitoring of fighter pilots. Considerable further work is required to establish validated acceptance criteria for spinal radiographs. Thus at present the Royal Netherlands Air Force is rejecting 20% of candidate student aircrew for spinal disease visualised by radiography.

The pilots of present and future fighter aircraft must have a very high standard of vision. Indeed several groups of investigators are attempting to develop and validate tests of vision which will allow the selection of individuals with above average vision in the context of fighter operations. The tendency which has occurred in the past of accepting individuals with a degree of myopia which results in the need for them to wear corrective lenses (before the natural process of ageing requires it at about 45 years) should cease, particularly with respect to fighter pilots. Now is an appropriate time to raise the vision standards for those destined to operate future fighter aircraft. Although further validation studies are required, the measurement of contrast thresholds using sine wave gratings promises to be of value as a means of measuring visual performance, particularly under low contrast conditions. There is a very strong case for the introduction in the immediate future of improved methods of assessing colour vision. A technique employing a coloured CRT display is most attractive. In the longer term, measurement of dynamic visual acuity should probably be employed in the selection of fighter pilots.

A recurrent question in the development of special medical selection and monitoring procedures, especially those which involve an element of risk or are expensive, is when they should be applied in the selection process? Factors which bear heavily on the answer to this question include the size of the air force, the acceptability of more than one medical fitness standard for aircrew and ethics. The ethical question relates to the use of procedures with an element of risk, for example radiographic examination which expose the individual to significant radiation, especially when the individual may not in any case qualify for, or

remain engaged in, the hazardous situation for which the selection procedure is to be used. Since fighter pilots must have a high standard of medical fitness there are very considerable advantages in a dual standard or permanent waiver system in which pilots who do not meet the very high standards required of fighter pilots can remain operating other military aircraft such as bombers, tankers, transports and helicopters. There are also considerable advantages in a dual track flying training system in which the specialised and expensive (and perhaps slightly risky) selection procedures are only applied after the student aircrew member has been selected for training as a fighter pilot.

There is no doubt that, if only on the grounds of general health, aircrew and fighter pilots in particular should take physical exercise to maintain a reasonable level of physical fitness. The moderately high level of physical work which is involved in the muscle tensing and straining manoeuvres required to protect against +Gz acceleration will produce less cardiorespiratory stress in the physically fit individual. It is now clear, however, that intensive aerobic training reduces the tolerance of high sustained +Gz. It is also apparent that exercises which increase the strength of the limb and trunk muscles enhance G tolerance. The muscles of the neck should also be strengthened by appropriate exercises to reduce the risk of damage to the cervical spine by exposure to +Gz. There is a need, therefore, for fighter pilots to carry out specific physical training programmes. This approach to the enhancement of physical fitness is more cost effective and acceptable than the use of a measurement of aerobic capacity in the selection of candidate pilots and fighter pilots.

The physiological training of aircrew should be integrated where possible with fitting them with, and training them in the use of, their life support equipment. The major areas in which changes are required in physiological training relate to protection against rapid onset, sustained high +Gz, disorientation and the use of NBC protective equipment. Extensive instruction in G protective manoeuvres will be required for the pilots of future fighter aircraft as indeed it is already required for those operating F-16 and F-15 aircraft. Training in the straining manoeuvres required at high +Gz is probably best given using a human centrifuge, and this form of training should be introduced for pilots operating rapid onset, high sustained G aircraft. Improved techniques for teaching aircrew the mechanisms and effect of disorientation, such as those employed by the Royal Air Force and those being introduced by the United States Air Force, should be mandatory for the training of the pilots of future fighter aircraft. Finally, the issue, fit and training in the use of aircrew NBC protective assemblies and the associated ground operating procedures should be centralised and aircrew should regularly wear the NBC assemblies on the ground and in flight.

AIRCREW ASPECTS OF UNITED STATES FUTURE FIGHTER AIRCRAFT

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SUMMARY

The cockpit environment of fighter aircraft for the year 2000 and beyond will undoubtedly meld aircraft technologies and protective devices to meet the ever-growing enemy challenge. Recent advances in aircraft structures, flight controls, sensors, multipurpose and touch-sensitive displays, voice recognition and synthesis, enemy defenses, and chemical/biological warfare (CBW) technologies will combine to create a cockpit environment for future fighter aircraft vastly different and potentially more complex than any previously encountered by our aircrews. This integration of equipment and crewmember will interact such that new stresses will be created and existing ones aggravated. For example, current CBW protective garb induces significant physiological stress, reduces tactile sensitivity, and restricts vision. Sensors, while providing more situational awareness, may create significant additional psychological stress. Even today, tactical fighters are capable of more rapid +Gz onset than ever before. Improved structure, reclined seats and side-stick controllers will enable both the pilot and the aircraft to withstand increased +Gz and more rapid +Gz onset. Special maneuver capability through the use of direct side force may provide significant tactical advantage at the expense of stress due to lateral acceleration forces(±Gy). This paper will identify and briefly discuss a few of the current technologies and some of the driving forces which will affect the cockpit environment of tomorrow's aircraft. These technologies, as well as others, should receive further study for their effects on the aircrew prior to application in future fighter aircraft. Proper application of the results of these studies will prevent the unbridled growth of cockpit complexity.

FLIGHT CONTROL

The technology to produce direct sideforce and direct lift on future fighter aircraft has already been demonstrated. These forces, although not new, are not customary for today's pilot. He has been repeatedly taught that coordinated flight is essential to smooth control. Only in unusual flight conditions, such as spins, slips, and air combat maneuvering, does the pilot intentionally induce uncoordinated flight. With the advent of direct sideforce and direct lift, the pilot can now have the capability to change the flight path vector without a comparable attitude change. Problems can arise, however, since the pilot is not permanently affixed to the interior of the cockpit, but has some sideward motion resulting from the effects of gravity along the transverse axis. Such body motion can affect both stick and rudder inputs to some degree, and therefore, the pilot's control of the aircraft. If using a head up display, the pilot's major concern is to keep his line of sight within the exit pupil of the display; his purpose being to launch a weapon against an adversary or target. Centrifuge test data at ±2Gy indicate that the addition of a simple shoulder pad restraint system significantly improves tracking performance on an airborne target at a cost of some side panel visibility and interference with flight clothing. Additional study is certainly required to design a more optimum restraint system.(1) At higher transverse G levels, the introduction of a helmet mounted display with the possibility of some restriction of helmet motion may be necessary.

The introduction of direct side force and direct lift brings with it the additional problem of what method should be used to control these forces. Experiments with the AFTI/F-16 indicate that pointing, flat turn and translation were very effectively implemented through decoupled rudder pedals and required minimal training. Control of vertical decoupled motion was effectively implemented through the use of a twist throttle. However, extraneous inputs were encountered during throttle movement. Human-factors-oriented design studies for suitable manual task controllers still need to be conducted.

HUMAN CENTRIFUGE EXPERIMENTATION

Greater control authority makes current fighter aircraft capable of higher +Gz onset rates than ever before. Coupled with six degree of freedom control, the forces generated will combine to present a very new environment for the fighter pilot of tomorrow. To better prepare today's pilot for the rapid onset +Gz environment, US Air Force tactical fighter pilots are currently undergoing training in a newly modified centrifuge at Brooks Air Force Base, Texas.(2) The improved system is now capable of reaching +9Gz, the typical maximum for current fighters, in only 1.3 seconds as compared to eight seconds previously.(3) Some testing of pilot reaction to transverse acceleration up to ±2Gy has been performed in the Air Force Aerospace Medical Research Laboratory Dynamic Environment Simulator. Investigation of the simultaneous interaction of rapid onset +Gz and ±Gy must still be addressed.

CHEMICAL AND BIOLOGICAL WARFARE DEFENSE

In addition to ±Gy and high onset Gz, tomorrow's fighter pilot must be prepared to encounter the hostile environment of chemical weapons. Although the use of chemical and biological weapons has been outlawed since the 1925 Geneva Protocol, the nations of the world continue to argue over the terms of a new, more comprehensive ban.(4) The likelihood that chemical weapons may be used in a future conflict cannot be overlooked. Such weapons are specifically intended to incapacitate or eliminate the crewmember, rather than to directly destroy the system itself. Since biological agents are typically slow acting, they are ill-suited for use against an airborne system. Considerable evidence exists which shows that our potential adversaries are preparing to operate in a chemical/biological environment. These actions cannot be taken lightly; since failure to prepare for the possible use of chemical weapons by our enemies makes us especially vulnerable. The possibility of their use dictates appropriate protection for the crewmember; for without him, the system cannot accomplish its mission. Protection for the crewmember becomes both a flight-critical and mission-critical requirement. Because of the nature of modern chemical weapons, the crewmember must be completely protected from his external surroundings, presumably within an impermeable suit or even a capsule with a suitable environmental control system. The environmental control system must be capable of detecting and neutralizing chemical agents or of providing a safe environment, either self-contained or recycled. Current protective equipment is bulky, vison restricting, easily damaged, and interferes with tactile sensitivity while causing significant heat stress. If this equipment must be used in cockpits in conjunction with touch-sensitive overlays and programmable switches, the limitations imposed must be considered in the design of the equipment.

VISUAL LIMITATIONS

A reclined seat for improved +Gz tolerance combined with current CBW equipment results in a considerable portion of the cockpit being obscured. In the fully reclined position, the pilot's ability to view lower portions of the cockpit front and side panels is severely restricted. Significant degradation of the pilot's ability to "Check 6" occurs in a fully reclined seat. He is not able to make a simple turning of the head to see behind the aircraft, and consideration must now be given to providing an additional display of the area behind him, or incorporate coverage of this area in the situation display. Because of these limitations, helmet mounted displays, currently in their early stages of development, will almost surely be essential in the cockpit of tomorrow.

SENSORS

Sensor technology improvements over the last several years together with increasing computer power, promise refined information tailor-made for the situation. Doppler beam sharpened, phased array and bi-static array radars offer precision well beyond the capability of previous airborne radars. Terrain Following/Terrain Avoidance (TF/TA) radars guide the aircraft through low-level mountainous terrain. Threat Avoidance computations will soon be added to TF/TA on an integrated situation awareness display. Night-Vision Goggles (NVGs) and Forward Looking Infra-Red (FLIR) sensors enable viewing of targets under low light conditions. Radar and Infra-Red warning receivers tell of hostile action threatening the aircraft. Numerous system sensors alert or warn of excessive or inadequate flow rates, pressures and temperatures. Traditional airborne sensors for airspeed, altitude, angle of attack, etc. may soon be followed by chemical agent detectors. All of this information has traditionally been presented on individual dedicated displays for the pilot to assimilate, integrate, evaluate, and take appropriate action. Such a situation threatens to create an excessive workload for the crewmember of tomorrow.(5) Computer processing of radar range and azimuth information enables it to be converted to X and Y coordinates for display on a Cathode Ray Tube (CRT), eliminating the need for a dedicated radar display. The potential even exists through additional computer processing to identify targets by computer. The use of such computer identification would allow display of the target by symbol rather than raw data, which burdens the pilot with the identification task. Experience has shown however, that the final identificatin of the target must be made by the pilot prior to weapon release.

MULTIFUNCTION DISPLAYS

With the advent of more and better sensors, the pilot now has available to him much more data than ever before. The partial solution to this explosion of sensor data is available in the form of the multifunction display (MFD). The MFD is rapidly taking the place of the dedicated displays of yesterday. The introduction of MFDs has in some measure actually encouraged the proliferation of sensors onboard aircraft as panel area for dedicated displays becomes increasingly scarce. A few multifunction displays can be used to display a myriad of information in a wide variety of formats. Although this is a valuable capability, the displays sometimes present their own unique problems of sunlight legibility, canopy reflections, brightness levels for night operations, compatibility with night vision goggles, etc. A word of caution is in order at this point; the proliferation of data has typically been allowed to grow upon the current displays, often without consideration of the clutter which ensues.(6) It is clear that properly designed pictorial formats must supplant raw data on multipurpose displays for ease of pilot understanding.(7)

TOUCH-SENSITIVE OVERLAYS AND PROGRAMMABLE SWITCHES

With the introduction of multifunction displays into the cockpit, the pilot now has available to him the option, sometimes even the necessity, of using touch-sensitive overlays or display perimeter switches to control various subsystems. Additionally, programmable switches employing dot matrix displays may even be used in conjunction with a computer for such sophisticated actions as selecting the best available weapons mix for attacking a troop convoy, a tank, petroleum storage, etc. The display of a pictorial symbol of the intended target may be used to relieve the pilot of the detailed selection of the weapon combination available to do the best job on preplanned targets or, even better, on targets of opportunity or for self-protection.

AUTOMATION

The growing use of computers in the cockpit of tomorrow promises considerable aid, and possibly even comfort, to the future tactical fighter pilot. Because of the large number of sensors, systems, weapons, etc., some form of management and monitoring of all of this data must be devised. To accomplish this, an electronic crewmember (EC) or pilot's associate appears to be in order. It is widely accepted that control devices are extremely well suited to monitoring tasks; whereas the human is extremely good at flexibility and intuitive problem solving, but much poorer at monitoring. A human is also likely to make occasional commissive errors. Current work by the Defense Advanced Research Projects Agency through the Air Force Wright Aeronautical Laboratories is investigating the application of artifical intelligence to the fighter aircraft of tomorrow. The introduction of such a computer or expert system into the cockpit raises the question of "Who's in Charge?" A careful division of the responsibility for the various flying tasks should reduce pilot workload significantly. These task allocations must be fully investigated in order to avoid a pilot role resulting in the loss of pilot skills from non-use.(8) Proper task allocation should reduce the number of pilot errors which are an additional significant source of workload and stress to experienced pilots.(9) There will also probably be a significant problem of gaining acceptability by current pilots of the EC's ability to perform some or even many of these functions. Such reluctance will probably be less pronounced among the pilots of tomorrow because of their early association with computers at a much younger age.

VOICE INPUT/OUTPUT

Research today is showing considerable promise for the availability of a large vocabulary connected speech input and output system for aircraft applications. Such capability will transcend the current application of operating switches and permit the pilot to interact with the EC employing artificial intelligence to assist him. The multiengine pilots of yesterday regularly referred to the autopilot as "George." The aircraft itself has been frequently referred to by nicknames, for example, "Babe", "Honey", etc. It is therefore highly likely that such a name or term will evolve for the EC. If not a standard name like "George", then one will likely be selected by each pilot. Such "friendship" with the computer system will lead to a more natural interface with the EC. The pilot will be able to preselect various levels of responsibility for the EC depending upon mission segment. For example, for system monitoring the pilot may instruct the EC to alert him to every system problem, to none, or to one of several levels in between, depending upon the anticipated pilot workload during the given mission segment. He may, of course, modify the EC's responsibility level for any mission segment at any time during the flight.

FLASH BLINDNESS PROTECTION

While we continue to design aircraft primarily for operations in a conventional weapons war, the possible use of tactical nuclear weapons cannot be ruled out. This places yet another burden on the crewmember. Assuming that the aircraft is far enough away from the detonation to avoid life-threatening shock and thermals, the pilot will surely be subjected to nuclear flash. The single-seat fighter pilot is especially vulnerable. It is possible to envision a future pilot flying a low-level TF/TA penetration at night using NVGs and a nuclear blast occurs. Without proper protection, the photomultiplier of the NVGs could be completely destroyed. In such a case, the night adaptation lost by the pilot by using NVGs could require from one to over four minutes to night adapt.(10) A rate of recovery this slow can be deadly in an aircraft at 200 feet altitude and flying in excess of 400 knots. It may be preferable to (a) completely enclose the cockpit, offering the pilot only sensor information for outside reference or, (b) equip the aircraft with PLZT windows which become opaque to nuclear flash, in order to protect the crewmember. Either solution will undoubtedly introduce environmental problems of its own.

CONCLUSION

Advancing technology will provide the pilot of future fighter aircraft with a much more capable weapon system. The progress of individual technologies will undoubtedly continue, but their introduction into the cockpit must be carefully tempered with appropriate human factors analysis. The introduction of these new technologies will especially require an open mind on the part of the pilots and considerable training to obtain maximum benefit from the investment.

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DISCUSSION OF SESSION I - FUTURE FIGHTER AIRCRAFT

(Papers 27 and 28)

AIR CDRE ERNSTING (UK)

Col Krobusek, how does the United States Air Force intend to resolve the conflict which arises between the provision of nuclear flash protection by means of a small window of PLZT in an otherwise black-out canopy and the need for good all round vision in the air combat situation? Is it that you see the solution to these two types of operation being in entirely different types of aircraft?

AUTHOR'S REPLY (LT COL KROBUSEK (US))

This particular problem has not been addressed fully. The two requirements are almost diametrically opposed. When you solve one for visibility you almost surely introduce problems in the other. My main purpose in the paper was to point out that we probably, and this is my view, cannot meet both requirements in a single aircraft.

COL VAN DEN BIGGELAAR (NL)

Mr Chairman, I would like to make a remark on the excellent paper by Col Viant. He mentioned a requirement in future aircraft for automatic recovery of the aircraft to level flight in the event of loss of consciousness. I would very much support this proposal since recent experience with the F16 has shown that G induced loss of consciousness and severe disorientation can result in tragic loss of lives and aircraft. A device which would automatically level an aircraft in an uncontrolled situation would, I believe, prevent many of the accidents of the types which have occurred in the last 2-3 years.

AUTHOR'S REPLY (COL VIANT (FR))

Yes, I did refer to this problem. In air combat situations rapid onset, high G can induce loss of consciousness. There is as yet no clear technical solution to the requriement for automatic recovery of control in this situation. One can, however, perhaps envisage a device such as the dead man's handle which is used in driving cabs of trains. Thus it is possible to envisage a system which, in the event that the pilot does not make any inputs through the control column say for 30 seconds, the aircraft computer takes over control and restores stable flight. We do not yet have the technical solution to this problem. I believe that it is an area where further research is required.

COL VAN DEN BIGGELAAR (NL)

Yes, I believe that it is technically possible to programme the flight computers so that the aircraft is brought to stable, level flight in the event of a period of unconsciousness or a period in which the pilot is so disorientated that he doesn't know where he is. I wish to comment on the value of a dead man's handle. We fitted a switch in our centrifuge which the pilot had to depress throughout the G profile. We expected him to release the switch if he lost consciousness. We had one case, however, in which the pilot did not do so; he continued to depress the switch after he lost consciousness, due to spasm of his hand muscles. Thus a simple dead man's handle will probably not be adequate to cope with this problem.

BRIG GEN BURCHARD (GE)

I enjoyed both of these excellent presentations. I believe, however, that the human limits are not being considered sufficiently in the concepts of the new fighter aircraft of the 1990s. Apparently we are not willing to accept that we are driving the human being to his utmost limits. I suggest that the AMP should state that the pilot should not be required to operate close to his limits of tolerance of high acceleration. I think we should require more from the weapon systems. The authors talked about the need to be able to fire in all directions. Why have a high turn rate and high G onset rate in order to turn the aircraft in order to direct a medieval rocket weapon at the target? Future technology should be used in the weapon system to relieve some of the tasks on the pilot. Cannot artificial intelligence be put into the weapon system as well as the aircraft and thus relieve the pilot and the aircraft from some of these physical stresses which pushes him to the utmost limit?

AUTHOR'S REPLY (LT COL KROBUSEK (US))

Yes, I would agree completely. The comments that I made during the presentation were offered to stimulate thought. They were only some of the areas which we should consider in future combat aircraft. As was pointed out by the Chairman, there are some solutions to some problems which may give us problems in other areas. I do not think that there is any single solution to all of the scenarios which we can develop; the human mind is just too smart for that.

AUTHOR'S REPLY (COL VIANT (FR))

Yes certainly we should consider the whole system - the aerodynamics of the aircraft, the aircraft performance and also the performance of the missiles with which the aircraft is armed. Even in a future combat aircraft it will be still necessary to manoeuvre the aircraft rapidly in order to achieve a hit on the target. We must also keep in mind the fact that we must build aircraft at a cost which we can afford. Thus we cannot always afford the sophistication of the aircraft which we would like. Finally. the effectiveness of an aircraft is the summation of the effectiveness of the pilot and the effectiveness of the machine. In these circumstances the spirit of combat and the physical capacity of the pilot enhance the effectiveness of the machine. If you have two aircraft each pilot will try to do better than the other. He will go up to the limits of human tolerance - this is part of the spirit of the fighting man.

CANADIAN FORCES APPROACH TO AIRCREW MEDICAL SELECTION

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SUMMARY

With advances in aircraft performance capabilities and in medical screening technology, major changes in Canadian Forces aircrew medical screening procedures have been proposed and are being introduced. In addition to the standard battery of tests, additional screening procedures being introduced or evaluated include drug screening for cannabinoids, contrast sensitivity function visual assessment, echocardiograms, cardiovascular risk assessment, pulmonary function testing, an aeromedical history questionnaire, and a psychosocial and clinical review by a Flight Surgeon. Screening electroencephalograms are being continued. This data is used to reject candidates who fail to meet selection standards, and to provide a Medical Suitability Rating for acceptable candidates. 2.8% of candidates screened have had positive tests for urinary cannabinoids. Contrast sensitivity norms for the aircrew candidate population are higher than for other populations studied. Contrast sensitivity may be helpful in assessing candidates whose vision is close to standards. We believe this approach to initial medical screening will reduce attrition of experienced aircrew for medical reasons, and will enhance flight safety over the years to come.

Historically, the RCAF conducted medical screening of pilot and navigator aircrew candidates at regional Medical Selection Units. These units were staffed by Flight Surgeons, who conducted the basic medical examinations, and by appropriate Specialists who completed ancillary investigations including ophthalmologic, otolaryngologic and psychiatric review. With triservice unification (and subsequent manpower reduction) in 1968 the Canadian Forces (CF) incorporated aircrew medical selection into the Central (Aircrew) Medical Board (CMB) at the Defence and Civil Institute of Environmental Medicine (DCIEM). This was staffed by a single Senior Flight Surgeon and appropriate technicians.

Basic enrolment medicals were then done at local Recruiting Centers, usually by civilian physicians under contract, and the medicals were administratively reviewed by a CF Medical Officer. This medical screening included a physical examination, an electrocardiogram, a chest x-ray, an audiogram, an ophthalmalogic evaluation, and a VDRL and urinalysis. Subsequently, while the candidates were undergoing aircrew aptitude screening at the Aircrew Selection Center in Toronto, the medical documents were reviewed by the CMB Flight Surgeon, and a few additional screening tests including anthropometrics and electroencephalograms were performed.

In the intervening years there have been significant advances in aircraft performance capabilities, and in medical screening technology. These advances have prompted major changes in Canadian Forces aircrew medical screening procedures. These changes reflect the CF philosophy that aircrew applicants should be maximally screened prior to enrolment, so that once accepted, trainees can be assigned to any operational flying role with further screening. Additional screening procedures being introduced or evaluated include drug screening for cannabinoids, contrast sensitivity function visual assessment, echocardiograms, cardiovascular risk assessment, pulmonary function testing, an aeromedical history questionnaire, and a Flight Surgeon review at CMB on each candidate. During this review an abbreviated psychosocial assessment and limited physical examination is done.

The battery of screening tests will be used not only to reject candidates who fail to meet standards, but also to formulate a Medical Suitability Rating (MSR) for candidates who are not rejected. This MSR will be provided to the Director of Recruiting Services to input into an integrated decision as to each candidate's overall acceptability/desirability.

This paper outlines our rationale for these particular screening procedures, the initial results of the drug screening and contrast sensitivity testing, and a follow-up of abnormal EEG's.

TABLE I CANADIAN FORCES AIRCREW MEDICAL SCREENING PROCEDURES

At Recruiting Center Level
- Enrolment Medical Examination
- Ophthalmologic assessment
- Audiogram
- Electrocardiogram
- Chest x-ray
- Laboratory - urinalysis, hemoglobin, blood sugar, cholesterol, VDRL

At the Central Medical Board
- Anthropometry
- Audiogram
- Ophthalmologic Assessment (if Required)
- Aeromedical History Questionnaire
- Pulmonary Function Tests
- *Echocardiogram
- **Contrast Sensitivity Analysis
- **Drug Screening (Cannabinoids)
- Cardiovascular Risk Assessment
- Electroencephalogram
- Flight Surgeon Review

* to be initiated in 1985
** under evaluation

Those screening procedures recently introduced or under evaluation at the Central Medical Board will be briefly discussed.

Aeromedical History Questionnaire

This questionnaire is attached as Appendix A, and is designed to supplement historical data obtained on the initial enrolment medical (CF 2027). Positive responses guide the Flight Surgeon during the subsequent interview to areas of potential pathology.

Pulmonary Function

Screening tests are aimed at detecting individuals with early fixed or reversible small airways disease who might later develop overt asthma, or be at increased risk of acceleration atelectasis. Current screening tests are the most sensitive available for the detection of small airways disease (10), and include maximum expiratory flow-volume curves on air and helium-oxygen, (repeated after bronchodilator if indicated), and the single-breath nitrogen washout. Candidates with a history of wheezing, or with abnormal screening tests undergo a methacholine challenge test, a measure of airway sensitivity. Candidates with positive challenge tests are rejected, as are those with significant fixed small airways disease. Those with mild abnormalties e.g. cigarette smokers with reduced flows at 50% vital capacity are given a lowered Medical Suitability Rating (MSR).

Echocardiograms

Of the various non-invasive cardiovascular procedures available to screen for structural cardiac abnormalities and arrhythmias, in addition to the resting standard ECG, the CF has opted to perform the M-mode and 2-D echocardiogram on all pilot candidates.

Exercise stress tests and ambulatory electrocardiographic monitoring of all candidates were rejected because of excessive manpower requirements, lack of data on what is truly abnormal on ambulatory ECG's, and the problem of follow-up of false positive ST segment changes on exercise stress tests. These tests will only be used to evaluate those candidates who have a history compatible with a potential arrhythmia, or in whom an arrhythmia is detected or suspected during the clinical examination, the resting electrocardiogram, or the echocardiogram.

Among the disqualifying structural lesions that may be detected by echocardiography are mitral valve prolapse, mitral regurgitation, aortic insufficiency, and cardiomyopathies including asymmetric septal hypertrophy, all of which potentially can lead to reduced G tolerance or loss of consciousness in the rapid onset high G environment (1).

Contrast Sensitivity Function

Contrast sensitivity is a measure of visual function which differs from standard acuity tests in that not only spatial frequency (a measure of Snellen chart letter size), but also contrast is varied. Sine-wave gratings (repeated sequences of light and dark bars) are presented to subjects on a CRT, the contrast of the grating being increased from below detectable visibility to threshold level. Gratings of different bar widths (spatial frequencies) are presented, and a plot of spatial frequency against contrast sensitivity (threshold) is obtained (Figure 1). This plot is analgous to an audiogram in which sensory threshold is evaluated at various frequencies. Ginsberg (2) has shown a relationship between target acquisition in the aviation environment and contrast sensitivity function.

Under a Test Program Agreement with the USAF, the CF has been conducting a trial of contrast sensitivity function in aircrew candidates since June 1984. The purposes of the trial are to establish population norms for contrast sensitivity in CF aircrew applicants, and to evaluate the potential application and usefulness in aircrew selection.

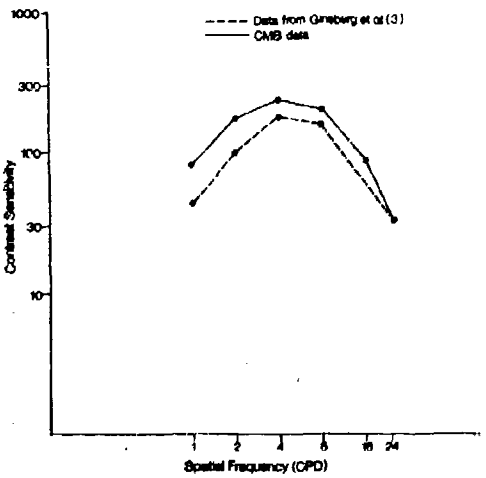

Figure 1

Compared with published population norms (3) CF aircrew candidates appear to have higher values for contrast sensitivity (or lower detection thresholds) (Figure I). These initial 100 subjects in the CMB study had an uncorrected visual acuity of 6/6, 6/9 or better, and were between 17 and 25 years of age. Ginsberg's (3) subjects were older (mean age about 36), and some wore corrective lenses, although their corrected visual acuity as a group was normal.

Although the contrast sensitivity test is not as yet used in the actual selection process, potential application is readily discernable in screening candidates with borderline visual acuity and/or cycloplegic refractive errors. Some candidates with borderline acuity or refractive errors have quite normal contrast sensitivity function while others fall well below the norm. Given the possible correlation between target acquisition and contrast sensitivity, it seems reasonable that candidates with borderline visual testing by classic methods, but clearly reduced contrast sensitivity, should be rejected, or given a lowered Medical Suitability Rating.

Drug Screening for Cannabinoids

During the period 1982-83, cannabinoids were the largest single drug group found post-mortem in aircrew who died in Canadian Forces aircraft accidents.

The CMB Aeromedical Questionnaire (Appendix A) includes two questions (#68, 69) about illicit drug use. About 25 percent of candidates admit to having tried marijuana or hashish in the past, but virtually all disclaim current use. In 1984, CMB initiated a trial study, screening each aircrew candidate's urine for cannabinoids.

Urines are screened initially by immunoassay (EMIT), and positives are confirmed by gas chromatographic mass spectrometry (GCMS). The EMIT method is an extremely sensitive assay, detecting total urinary cannabinoids for up to 10 days after consumption. It is not 100% specific and false positives do occur. The GCMS method is less sensitive because it determines one specific THC metabolite, but it is essentially totally specific.

Over the initial 8 month period of the trial, 534 candidates were screened. 18 of 534 (3.3%) had positive responses to the EMIT method, of which 15 were confirmed by gas chromatography.

No individual selection action was taken based on the results of this trial. CMB now obtains two separate urine samples from each candidate. Positive specimens confirmed by gas chromatography are sent to an independent outside laboratory for further confirmation. The Director of Recruiting and Selection will be informed of candidates who have two confirmed positive samples, so that this factor can be considered during selection proceedings.

Cardiovascular Risk Assessment

Cardiovascular risk factors including blood pressure, smoking habits, total cholesterol, family history, fasting blood sugar and exercise habits are collected on each candidate. HDL cholesterol assays are being introduced. Candidates with familial hypercholesterolemia and a positive family history of coronary artery disease are rejected, as are hypertensive candidates (persistent readings over 140 systolic, 90 diastolic). In otherwise acceptable candidates, the MSR is adjusted downwards based on the presence of risk factors, i.e. total cholesterol over 275 mg/dl (or total/HDL ratio over 6), current use of tobacco products, a coronary event in a first degree relative before age 50, and borderline hypertensive blood pressure readings.

Electroencephalograms

The application of the electroencephalogram to the aviation medicine environment has undergone cyclic waves of enthusiasm over the past 45 years. Early attempts to correlate EEG findings with the outcome of flying training proved unsuccessful (4). The technique was later applied as a screening tool for a seizure disorder in aircrew candidates. Several follow-up studies (5,6,7) have been reported, and although the predictive value has been extremely low, most of these reports have recommended continued use of the screening EEG. Because of the low predictive value in the population being screened, many military aviation agencies have discontinued using the EEG as a screen in candidates. In a recent cost-benefit analysis, Everett and Jenkins (8) recommended that the USAF perform EEG's on fighter pilot candidates only.

The Canadian Forces continue to perform screening EEG's on all pilot candidates. The EEG's are done with needle electrodes in the "10-20" placement system, with both hyperventilation and photostimulation. All EEG's are read by the same neurologist, and are classified as follows:

a. Type I - minor or generalized non-specific abnormalities

b. Type II - abnormal - focal non-specific abnormalities, minor assymetries, or 4-7 Hz waves occuring spontaneously, during photic stimulation or HV and persisting more than one minute after cessation of HV

c. Type III - unacceptable - specific EEG waveform abnormalities including focal spike discharges or generalized spike and wave discharges.

Despite the manpower commitments and low predictive value, because of the potential catastrophic nature of a seizure during flight, the CF will continue to do EEG's on pilot candidates. Candidates with Type III EEG's will be rejected from pilot training.

The percentage of EEG's read as type III by the same CMB consultant neurologist over the period 1974-84 has averaged 4.4 per cent annually, with a range of 0.6% to 10%. Although the CF has been doing EEG's on aircrew candidates for 30 years, the early data has been lost to follow-up. In 1984, CMB initiated a retrospective study on type III EEG's obtained since 1978. 121 questionnaires were mailed to determine whether any of these individuals have subsequently had a seizure or unexpected loss of consciousness. To date, 50 responses have been obtained, none of which report such an occurrence.

Flight Surgeon Examination and Psychosocial Interview

The CF believes that a careful assessment of each candidate by an experienced Flight Surgeon is a critical part of the medical screening process. Rather than reporting a complete physical examination, the CMB Flight Surgeon concentrates on a detailed cardiovascular and musculoskeletal evaluation, and on clarifying any potential health problems suggested on the enrolment medical or Aeromedical Questionnaire. During this interview, the Flight Surgeon asks a series of questions, as suggested by Mills and Jones (9), designed to elicit aberrant motivation or psychopathology in aircrew candidates. If pathology is suspected, a further evaluation by a CF aviation oriented psychiatrist/Flight Surgeon is requested.

These various procedures have just recently been introduced, or are still in the process of being evaluated by the Canadian Forces Central Medical Board. It will be some years before the effect of these changes can be assessed in terms of medical attrition of experienced aircrew, and improved flight safety records, but we believe that the application of state-of-the art medical technology and screening techniques may have a significant impact on both of these areas. Assessment of the efficacy of the newer screening techniques should be aided by a computorized system for aircrew medical records currently under development at CMB.

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CENTRAL MEDICAL BOARD AIRCREW CANDIDATE EVALUATION

CMB/ACE

BIOGRAPHIC DATA

Surname: Given Name, Initials: DOB:

SIN: Country of Birth: Racial Origin:

Sex: CFRC/Unit:

Current Address, telephone:

Name, address, telephone of next of kin:

PREVIOUS FLYING EXPERIENCE

Types of licence(s) held:

Types of aircraft flown and approximate hours on each:

FAMILY HISTORY: Does your family have a history of;

	Yes	No		Yes	No	Comments (#detail)
1. Allergies/asthma			8. Psychiatric Problems			
2. Bleeding disorders/anemia			9. Rheumatism, arthritis			
3. Diabetes			10. Stomach, bowel disorder			
4. Epilepsy/seizures			11. Chest, lung trouble			
5. Heart trouble			12. Tumour/Cancer			
6. High blood pressure			13. Alcoholism			
7. Stroke			14. Suicide			
			15. Kidney stones			
			16. Sudden death			

PERSONAL HISTORY/HABITS

1. Number of years tobacco products used:
   Number of years since stopping smoking:
2. Average tobacco consumption when smoking
   Cigarettes/day or equivalent 1-10 11-20 20+
3. On the average, how many times a week do you drink any alcoholic beverages:
4. When you drink, how many drinks do you have on the average:
5. How many days a week do you exercise vigorously for at least 15 min:
6. Do you use a seat belt when driving
   Rarely Usually always
7. Do you use any medications (including birth control pill) regularly?:
   If so, what:________________

.../2

APPENDIX A

CML/ACE/2 AEROMEDICAL SYSTEMS REVIEW Have you ever had (been) or do you now have

	Yes	No
1. A racing or thumping heart		
2. Pain or discomfort in your chest		
3. Investigations for heart problems		
4. A heart murmur		
5. High blood pressure		
6. Unusual shortness of breath		
7. Fainting or dizzy spells		
8. Leg cramps with exercise		
9. Frequent or severe headaches		
10. Migraine		
11. A seizure or convulsion		
12. A head injury		
13. Periods of unconsciousness		
14. Depression or excessive worry		
15. Any mental condition or illness		
16. Psychiatric help		
17. Considered suicide		
18. A sleepwalking problem		
19. Loss of memory/amnesia		
20. Hearing trouble		
21. Exposure to loud noises		
22. Ear, nose or throat trouble		
23. Difficulty with your ears or sinuses during flying or diving		
24. Frequent nosebleeds		
25. Sinus problems or sinusitis		
26. Unsteadiness or trouble with balance		
27. Paralysis or weakness		
28. Hayfever or allergic rhinitis		
29. Allergies to drugs, serum, foods bites or stings		
30. Allergy testing/desensitization		
31. Used antihistamines or nasal congestants for allergies		
32. Trouble with your eyes		
33. Been tested for glasses		
34. Glasses or contact lenses		
35. Any procedure to improve your vision		
36. Do colds tend to settle in your chest		
37. Wheezing or asthma		
38. An inhaler for your breathing		
39. Prolonged cough		
40. Coughed up blood		
41. Chest/Lung problems during childhood		
42. Contact with tuberculosis		
43. TB or a positive TB test		
44. Lung function tests		
45. Rheumatic Fever		
46. Stomach, liver or bowel trouble		
47. Gall bladder trouble or gallstones		
48. Jaundice or hepatitis		
49. Hemorrhoids or rectal disease		
50. Frequent indigestion or heartburn		
51. An ulcer		
52. A stomach or bowel x-ray		
53. Vomited blood		
54. Colitis		
55. Bloody or black stools		
56. Severe constipation, frequent diarrhea		
57. Trouble with your back		
58. Trouble with bones or joints		
59. X-rays of your back		
60. A bladder or kidney infection		
61. A kidney stone		
62. A venereal disease		
63. A hernia or rupture		
64. Thyroid trouble		
65. A tendency to be overweight		
66. A diet to lose weight		
67. A recent weight gain or loss		
68. Tried marijuana or hashish		
69. Tried LSD, cocaine, PCP amphetamines or similar drugs		
70. Used medication for over 3 consecutive months		
71. Trouble with skin problems		
72. Trouble with severe acne		
73. A surgical operation		
74. A hospital admission for medical illness		
75. Been pregnant		
76. Gynecologic investigation or treatment		
77. Painful periods requiring time off school or work		

POSITIVE DETAILS (#, explanation):

I hereby declare that I have carefully considered all the responses made in Parts a through e, and that to the best of my belief, they are complete and correct, and that I have not withheld any relevant information or made any misleading statement.

Date:______________ Witness______________ Signature block______________

MEDICAL SELECTION AND PHYSIOLOGICAL TRAINING OF FIGHTER PILOTS - A 1985 PERSPECTIVE AND OVERVIEW

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INTRODUCTION

Early in World War I analysis of British data revealed 60% of all fatal aircraft mishaps were directly due to some physical defect. This led to the establishment of a specific medical service for "care of the flyer." In two years, total mishaps due to physical defects fell to 12% - an impressive achievement. This was the beginning of flight medicine and the physician called the "flight surgeon."

Much progress has been made in aviation technology and aerospace medicine during the past 65 years. The USAF is proud that the aircraft mishap rate has been reduced to a relatively low level - 1.7 mishaps/100,000 flying hours in 1983 and about 1.8 in 1984. That is an excellent achievement considering the aggressive and realistic training scenarios we have today.

Today, in spite of our relatively low rate, we still lose almost a wing of aircraft per year - 57 destroyed in 1984 at a cost of about $410 million. Table I.

1984 USAF AIRCRAFT MISHAP DATA

Total Class-A Mishaps	62	(57 destroyed)
- Rate/100,000 hrs	1.8	
FTR/ATK* Class-A Mishaps	43	
- Rate/100,000 hrs	3.5	
Total Fatals	79	
- Pilot Fatals	38	
- FTR/ATK Pilot Fatals	25	

*Fighter and Attack Aircraft

Table I

The decline in the mishap rate over the last decade is largely due to a reduction in the "LOG Rate" (Logistics/Maintenance Factors) - 1.6/100,000 in 1975, 0.5 in 1983 and 1984. Today we have better aircraft systems, and they are better maintained. Good leadership and supervision have undoubtedly played a role.

However, as the mishap rate has declined in recent years, the proportion of mishaps due to human-factor variables has increased - 67% in the FTR/ATK for 1984. Table II.

FTR/ATK CLASS-A MISHAPS

FTR/ATK Total	43	
Human Factors	29	(67%)
LOG Factors, other	14	(33%)

Table II

The high proportion of mishaps due to human factors is a direct challenge for the aerospace medicine community. Another important challenge is ensuring that our pilots are able to effectively perform in the high-G_z environment. We believe we can meet both of these challenges by a strong focus on the "human element" - the man in the cockpit.

THE CHALLENGE

In the past 10 to 15 years, we've seen an exponential increase in aviation technology and fighter aircraft capability. Our new fighters are superb aircraft. They are fast, have an expanded flight envelope and are capable of rapid onset and high sustained G. All of these factors provide obvious advantages in the combat arena.

On the other hand, man's capability remains a constant. He must cope with an inherent set of physical, physiological and psychological limitations. The physiological stresses, workload and perceptual demands on the pilot during many mission scenarios are formidable. In fact, for the first time, man is the potential limiting factor in realizing the full capability of a fighter system. Yesterday we worried about over "G-ing" the aircraft; today (particularly in the F-16) we worry about over "G-ing" the pilot.

The really good fighter pilots I've known in the past have always been good aviators, smart, aggressive and have had an inherent desire to excel - "be the best." In

the future, it will also be important for fighter pilots to be physically healthy, in excellent physical condition and have a sophisticated understanding of aerospace physiology - particularly high-Gz physiology. Pilots have traditionally had a good understanding of their airplane's flight envelope. Today, and in the future, they must have a thorough understanding of their own personal physiological flight envelope.

FOCUS ON HUMAN FACTORS

The most significant human-factor (HF) problem facing the TAF today is spatial disorientation (SD) followed closely by high-G loss of consciousness (GLC). Thirty percent (30%) of all HF mishaps in the F-16 are due to SD. Nineteen percent (19%) of the HF mishaps in the F-15 and F-4 are due to SD. Other human-factor variables, such as distraction, channelized attention, loss of situational awareness and visual illusions, are also frequent causes or contributing causes of TAF mishaps today. Accelerative forces are the basis for most of these HF problems. Table III.

HUMAN-FACTOR PROBLEMS RELATED TO ACCELERATIVE FORCES

1. GLC on a physiological basis
2. GLC on a basis of preexisting medical problems (cardiac defects, cardiac arrhythmia)
3. Grey-out/blackout - channelized attention - "loss of situational awareness"
4. Spatial disorientation - illusions
5. Musculoskeletal pain/injury - distraction

Table III

An approach to reducing the problems related to high-G_z must be multifaceted:

1. Better medical selection.
2. Better education and training.
   - Fighter-specific physiological training
3. Improved life-support equipment.
4. Good physical conditioning.
5. Research and development (R&D)

WHERE WE HAVE BEEN - PAST INITIATIVES

1. 1977 was an index year for the USAF medical service. Three things of importance occurred which sharply focused our attention on the "human element."

a. During a short period of time in 1977, there were three fatal mishaps involving crew members with advanced coronary artery disease (CAD). One 45-year-old wing commander experienced a heart attack on final approach and died shortly after landing. Three young crewmembers, age 24 to 25, were found to have advanced coronary disease at autopsy following two fatal F-4 mishaps.

These mishaps led to high-level interest in the USAF and direction to develop a program to identify crewmembers at risk for developing CAD, and direction to develop more sensitive methods to detect existing coronary disease.

b. Also in 1977, consultants at USAFSAM first expressed concern about the increased stresses associated with the new high-performance fighters (F-15/16) which were entering the inventory. Of particular concern were the high-G forces and the increased probability of pilot incapacitation due to unrecognized cardiovascular defects.

During 1977 we also began to receive official and unofficial reports of a sudden loss of consciousness due to high-G forces in these new fighters. The GLC occurred without the classic preliminary warning provided by "grey-out" and "blackout". This new phenomenon was studied and documented in the Crew Technology Division of USAFSAM. Since then, we have learned that "sudden GLC" occurs in a wide variety of fighter systems and, until recently, such events have been seriously under-reported. We strongly suspect that many fatal mishaps over the past decade signed out as "cause unknown" were due to GLC.

2. These events in 1977 eventually led to a workshop on "Pilot Selection and Flying Physical Standards for the 1980s" which was held at Brooks AFB in 1979. About 50 senior medical consultants and line officers from 20 Air Force agencies participated.

During the workshop, consultants identified a number of medical conditions which would be detrimental to a pilot flying fighter aircraft. Our Class I flying physical standards were found to be adequate. Most of the conditions were listed in AFR 160-43 as medically disqualifying for flying training. There were three primary concerns:

a. Many of the medical conditions could not be detected by the Class I flying examination procedures in use.

b. Some of these conditions, primarily cardiovascular, could result in pilot incapacitation and a fatal aircraft mishap.

c. Other conditions, musculoskeletal for example, could be aggravated by repeated exposure to high-G resulting in premature attrition of fighter pilots from the TAF.

The workshop made a number of important recommendations, including:

a. Additional examination procedures for fighter pilot selectees.

b. High-G training for fighter pilots.

c. More conservative visual standards and waiver policy. A 20/20 standard without glasses for fighter-pilot selectees.

d. A categorical waiver system for rated flyers.

3. Considerable progress has been made since the workshop at Brooks AFB in 1979:

a. In 1981, a categorical medical waiver system replaced the rigid "fly one, fly all" waiver system. Medical waivers can now be granted in four flying categories. Table IV.

CATEGORICAL MEDICAL WAIVERS

Flying Class II	All aircraft systems
Flying Class IIA	Tanker, Transport, Bomber
Flying Class IIB	Tanker, Transport
Flying Class IIC	Other - aircraft system(s) specified

Table IV

b. A Coronary Artery Risk Evaluation (CARE) Program was implemented USAF-wide in January 1982. Crewmembers receive a CARE evaluation as a part of every complete physical examination. Relative risk for developing coronary disease is determined on the basis of age, blood pressure, cholesterol and smoking history. Total cholesterol/HDL cholesterol ratios are also obtained as an additional aid in estimating risk. Those at high risk are counseled, treated appropriately and followed annually. Consultation with USAFSAM is obtained for those at very high risk.

c. Since 1975, visual waivers had been granted routinely (20/50 DVA, -1.25 RE) to any pilot-training candidate. USAF Academy candidates received waivers beyond this limit; one up to 20/200 DVA! By 1980, concerns about this lenient waiver policy reached a high level. That year, about 600 of 1,575 (38%) pilot-training graduates required glasses to fly. At the USAF Academy, only 26% of the class of 1980 (904 students) were qualified for pilot training without a waiver. Seventy-three percent (73%) of the medical waivers were for visual problems.

In 1982, top Air Force leaders stopped this lenient visual waiver policy. Pilot candidates entering the USAF Academy, ROTC and Officer Training School are now required to meet the 20/20 standard without waivers.

d. During 1983, a working group of consultants from USAFSAM, the Air Force Surgeon General's office and the Air Training Command Surgeon's staff met on a number of occasions to develop improved medical selection procedures for pilot training. Revised selection standards for familial hypercholesterolemia and the musculoskeletal system were established. The working group agreed that additional cardiac and spinal examination procedures were required for fighter pilot selectees. It was also agreed that the echocardiogram would be the best, single cardiac procedure to use. Dr. Hickman will provide specific rationale for this position in his presentation.

e. In 1983 selection standards for hyperlipidemias were implemented and we began cholesterol testing for all candidates for flight training. Those found to have hyperlipidemia are disqualified for flight training. Fully trained flyers found to have hyperlipidemia are not disqualified. They are evaluated at their local bases and followed closely.

f. The 1979 Brooks workshop recommendation for high-G training was ignored by TAC leaders for several years. A number of fatal mishaps due to GLC over the past two years "shocked" and highly sensitized the TAF community to the high-G problem. In 1983 an anonymous survey (Air Force-wide) accomplished by the Air Force Safety Center revealed GLC to be a common occurrence in a wide variety of fighter aircraft. Educational efforts, including briefings, magazine articles and videotape presentations were intensified in 1983.

Also in 1983, the commander of TAC (Tactical Air Command) endorsed the need for high-G (centrifuge) training for fighter pilots. He also agreed to a proposal to establish

a Physiological Training Center (PTC) for the Lead-in Fighter Training (LIFT) course at Holloman AFB - which would include high-G training.

As an interim measure, high-G training is now being accomplished at USAFSAM. European-based crews are receiving training in the Dutch centrifuge. Pacific-based crews will soon begin training in Japan. The centrifuge at Brooks was upgraded in late 1984 and is now capable of an onset rate of 6Gs per second. Training includes typical high-G fighter profiles up to $9G_z$ and a "tracking" task. Current training efforts have been well received by the fighter community and have revealed that many experienced fighter pilots are not using the correct technique in performing the "straining" (L-1/M-1) maneuver.

CURRENT AND FUTURE INITIATIVES

1. General Jerome F. O'Malley assumed command of TAC in October 1984 and listed high-G and GLC as one of the top problems facing the TAF today. By his direction, a headquarters TAC working group was formed to study the issue, propose additional actions and closely monitor on-going initiatives and research efforts.

2. Plans to establish a Physiological Training Center (PTC) at Holloman AFB for the LIFT course are on track. We expect this facility to open in mid-1986. The PTC will provide fighter pilot selectees "fighter-specific" physiological training about one year after initial physiological training which they receive early in pilot training. This course will emphasize human-factor problems of importance in the fighter environment, such as:

a. GLC

b. Spatial disorientation

c. Visual illusions, distraction, perceptual problems

d. Hypoxia/hyperventilation

e. Self-imposed stresses

f. Physical conditioning

The course will include "case discussions" of recent mishaps involving GLC, SD and other human-factor variables. Training aids will include a centrifuge, altitude chamber, a spatial disorientation training device and new training films and videotapes.

3. Recently TAC requested Air Force Systems Command (AFSC) to review all aspects of high-G tolerance and protection and accelerate R&D efforts where appropriate. We specifically asked AFSC to focus on the following issues:

a. Does 100% O_2 provide any advantages or disadvantages in the high-G environment?

b. Are the reported advantages (less fatigue) of positive-pressure breathing significant enough to consider modification of any current fighter aircraft?

c. Status of R&D efforts for a new generation G-suit?

d. A better definition of the physiology associated with the first few seconds (1-10) of rapid onset of high-G forces.

e. A study of pilots with very low resting pulse rates. A number of pilots recently involved in fatal GLC mishaps were noted to have very low (<50/min) resting pulse rates in the absence of a regular exercise history. What is the significance of this observation?

f. Recent air-to-air GLC fatal mishaps have involved pilots in the neutral or defensive posture. F-16 pilots generally do not use the 30° tilt-back seat when in a neutral or defensive maneuvering position. In what way and to what degree does bending forward and looking over the shoulder affect the straining maneuver and G-tolerance?

g. The requirement for <u>initial</u> high-G training is fully accepted by the fighter community. Is <u>recurrent</u> high-G training required, and if so, at what frequency?

<u>Note</u>: A high-flow anti-G valve to replace the standard valve in the F-16, F-15 and A-10 aircraft has been approved. Delivery and installation of the first valves are scheduled for May 1985. AFSC is continuing research efforts with a high-flow, ready-pressure (HFRP) valve and two servo-controlled anti-G valves. One, a US Navy-developed valve which has an accelerometer to sense G forces and provide immediate maximum flow to the G-suit, has promise. The other is an electronically controlled high-flow servo valve. A G-onset sensor actuates the "press to test" button and provides full pressure for 2 seconds. Initial evaluation of this valve in the ASD centrifuge by USAF pilot physicians was also promising.

In 1982, an exercise program appropriate for fighter pilots, involving weight lifting and moderate aerobic exercise, was defined and provided to operational units. Such a

program will clearly increase a pilot's tolerance and endurance to high-G, i.e., he can handle high-G forces for a longer period before the onset of fatigue. Two significant benefits are obvious. First, the pilot's capability to effectively perform in the modern fighter environment is enhanced. Secondly, the potential for GLC incidents is reduced. An analysis of the last five air-to-air GLC mishaps revealed none occurred on the first engagement. One mishap occurred following the second engagement, two on the third and one on the fourth.

One could construct a future air-to-air engagement between two adversaries flying comparable fighters where the outcome is decided solely on the basis of who is in the best physical condition, has the greatest endurance and can "pull" the most "Gs."

The value of a conditioning program to increase the strength of neck muscles is especially important today. Neck "sprains and strains" have been a common occupational hazard for fighter pilots for many years. In the past, most neck injuries have been minor. Today we are beginning to see some serious neck injuries. One TAC base has had five serious injuries in the past year. Two involved compression fractures (10% and 25%) of cervical vertebra; two involved herniated cervical disc; and one a serious strain of an intraspinal cervical ligament. Most of these injuries could have been prevented by a good conditioning program.

Today the value of a regular exercise program for fighter pilots is recognized and encouraged by TAF leaders. Compliance has been poor in the absence of a mandated program. Busy flying schedules and work days and the absence of good exercise equipment which is readily available are significant obstacles which I feel we can overcome. We have proposed a mandatory physical conditioning program for fighter-pilot trainees which should be approved in the near future.

5. A final issue involves the requirement for additional medical examination procedures for fighter-pilot selectees. As I mentioned before, consultants at the 1979 Brooks workshop identified a number of medical conditions which are detrimental to a pilot flying fighter aircraft. Some of these conditions could result in pilot incapacitation; other conditions could be aggravated by repeated exposure to high-G resulting in premature attrition of pilots from the TAF.

The prevalence of these conditions is known to be about five percent (5%) in a young pilot-candidate population. Our current examination procedures (Class I flying exam) are not adequate to detect many of these conditions. A review of 28,069 exams accomplished on USAF Academy applicants revealed we are missing about 3.7% of these conditions. Table V.

USAF ACADEMY APPLICANT PHYSICAL EXAMS*
1981-1982 CYCLE
CONDITIONS AGGRAVATED BY HIGH-G FOUND

Cardiovascular	140
Non-cardiac	45
Musculoskeletal	175
Total	360**

* 28,069 exams reviewed.
** 360 ÷ 28,069 = 1.3% (conditions found)
- prevalence = 5.0%
- 3.7% conditions missed

Table V

Most conditions of concern can be detected by the addition of two examination procedures--an echocardiogram and spine series.

As I have mentioned, back and neck pain have been common in fighter pilots for years. We are beginning to see some serious neck injuries. We really don't know the long-term effects on the spine of repeated exposure to high-G. A spine series would serve two purposes. First, to select trainees with normal spines and, second, to establish a baseline for future comparison should symptoms develop or injuries occur.

IN CONCLUSION

From an aeromedical perspective, we have two major goals for the Tactical Air Force. The first is to reduce the aircraft mishap rate due to human-factor variables. The second is to enhance our pilots' capability to perform in the modern fighter environment.

Fighter pilots can perform in the $9G_z$ environment effectively and safely if they are properly selected, educated and trained. Our fighter pilots today, in addition to being good aviators, smart and aggressive, must be physically healthy and in excellent physical condition. They must have a thorough understanding of high-G physiology and their own personal "physiological flight envelope." Accomplishing the variety of initiatives required to realize these goals is an exciting challenge for the aerospace medicine community.

DISCUSSION OF SESSION II - MEDICAL SELECTION: GENERAL ASPECTS
(Papers 29 and 30)

QUESTIONER NOT IDENTIFIED

Col Hickman, could you please give more specific information on the question of hypercholesterolaemia?

AUTHOR'S REPLY (COL HICKMAN (US))

Yes, in fact in my own paper which follows this session, I'll discuss a proposed criterion for the rejection of pilot applicants for hyperlipidaemia. The problem basically is attempting to predict in individuals who are 21 years old, who is going to have coronary artery disease later in life. We look at premature coronary artery disease in the family as occurring if there is a first degree relative, a father, mother, brother or sister, with a coronary event under the age of 65. Most of our applicants of 21 years of age do not have family histories because their families are generally not old enough to have met that criterion. Family history has been of little value. Further, in any regression equation, a yes/no answer, which is a dichotomous variable, if misidentified causes a major perturbation in the equation. Family history has not been very helpful for those two reasons. Hypertension, by the time we are considering people for pilot training, is at a very very low rate and has been of minimal value. Smoking; we've not yet disqualified people from flying training because they smoke. About a decade ago about 20% of the cadets at the Academy smoked; today only about 6% of the cadets smoke tobacco. So when you come right down to trying to predict, at age 21, who is going to develop coronary artery disease late in life you are pretty much resigned to using lipids. The previous criteria that we have tried to apply (combining lipid levels with other family history, smoking and blood pressure) increase the predictive value to such a small extent that by and large we are looking at the cholesterol and high density lipoprotein (HDL). We are presently looking at the predictive value of subfractions of HDL. In our current proposed standard 300 mg percent in an applicant for pilot training will be considered the cut off level. Thus, if the cholesterol is 300 mg percent or greater, or the ratio of cholesterol to HDL is 6 or greater, that individual is counselled in the effects of diet, body weight and exercise and also the effects of smoking on HDL, because smoking lowers HDL. And then a month or perhaps 2 months later a repeat of the lipid values is obtained. Hyperlipidaemia is diagnosed if the serum cholesterol is 300 or greater or the ratio of cholesterol to HDL is 6 or greater. An individual with hyperlipidaemia is not accepted into pilot training. Obviously he is the worst possible investment.

COL VAN DEN BIGGELAAR (NL)

I would like to ask Dr Hickman whether spinal X-rays are being taken in the USAF? If so, do you have a washout rate of about 5% as you predicted? We have found that our washout rate using purely radiological changes in the spinal column is much higher than 5%.

AUTHOR'S REPLY (COL HICKMAN (US))

I believe, as is the case with many criteria which are totally arbitrary at the beginning, it will be excessive. Depending upon where you set your criteria, the losses to training can be adjusted. What we really need, in order to answer your question, is a dual track training approach so that age matched cohorts of individuals who enter tanker, bomber and transport training at the same time, at the same age with all matched attributes can be looked at and compared to fighter pilots. Only in the long term epidemiological approach can anyone give an intelligent and reasonable answer to your question. We have not yet started conducting spinal X-rays. One of the arguments that recurs continually is that most of the operators, the line officers, want all of the medical selection tests performed before the applicant attends the first class in pilot training. And yet we cannot ethically impose the associated radiation exposure on the half of our aircrew who are never going to fly in tactical aircraft. We are trying to reach some sort of agreement with the operators on this question and have not yet introduced spinal X-rays into pilot selection.

COL VAN DEN BIGGELAAR (NL)

The dual track system is practicable for large air forces but I think most of the smaller European air forces cannot afford this luxury. Their aircrew train for one specific type of aircraft which in most cases is the fighter aircraft since the smaller nations only have a very small fleet of transports or bombers.

AUTHOR'S REPLY (COL HICKMAN (US))

You will notice in the following presentation that I am going to give, the dual track system will eliminate some aircrew who have already had a small amount of flying training. The branching point into tanker, bomber, transport and fighter attack/reconnaissance will occur relatively early. For most air forces I feel that rejecting someone who has had any training is not cost effective but when we weigh the few individuals who will be removed at the branching point the expense is not nearly as great as the enormous burden which would be associated with cardiovascular and spinal screening of those individuals on the day they begin pilot training. For instance, we would have to put a cardiologist at each of our Air Training Command bases for cardiovascular screening and these bases have a predominance of very young subjects so that there is no other requirement for a cardiologist. Our problems are very different and I think everyone would agree that you have to look at your own situation.

LT COL VAN DEN BOSCH (BE)

I would like to ask Dr Gray for an explanation as to why the proportions of candidates rejected by the medical board for EEG abnormalities is the same as that for defective vision? This finding is rather surprising as we reject less for EEG abnormalities than for vision defects. I also have another question. Dr Gray said that candidates with hypertension will be rejected. I would like to know how many times the blood pressure is measured and how it is done, every week for example? What levels of blood pressure are considered as disqualifying?

AUTHOR'S REPLY (LT COL GRAY (CA))

The blood pressure criteria which we use are a systolic >140 mm Hg or a diastolic >90 mm Hg on repeated determinations - not only at the Central Medical Board but before on the initial enrolment medical and then again afterwards at further follow-up either by the family doctor or back at the Recruiting Centre. So if we document a sustained, repeated systolic pressure above 140 mm Hg or sustained, repeated diastolic pressure above 90 mm Hg we reject the candidate. Was there another question?

LT COL VAN DEN BOSCH (BE)

Yes you reject as many candidates for EEG abnormalities as for the vision defects. The experience of other air forces including our own is that more rejections are for vision than for EEG abnormalities.

AUTHOR'S REPLY (LT COL GRAY (CA))

Right, I understand your question. The rejections are approximately equal at Central Medical Board because the candidates' vision has already been screened at the Recruiting Centre before they come to Central Medical Board so that the number of visual rejections at the Board is only a small proportion of all those rejected for visual defects. The electroencephalograhpic rejections which were high in the past are now lower because we are now reject only those candidates who have type 3 specific abnormalities. These are then confirmed on follow-up EEG with sleep deprivation.

DR ALNAES (NO)

A question for Dr Hickman regarding Gen DeHart's paper. You said, as I understood it, that the waivering policy for visual criteria was such that the situation in the USAF a few years ago was that 25% of fighter pilots were spectacle wearers and that enforcement of the new visual waiver policy would decrease this incidence. How much has the proportion of spectacle wearers decreased over the last few years?

AUTHOR'S REPLY (COL HICKMAN (US))

I'm sorry I don't know the answer to your question. I doubt that the numbers have changed significantly since the policy is very new. It was introduced in 1982. I doubt that its been in operation long enough to make a difference. I will certainly find the answer to your question for you.

DR ALNAES (NO)

But I do understand you correctly in the sense that the waivering policy now in 1985 is quite different from the waivering policy of 1982/81?

AUTHOR'S REPLY (COL HICKMAN (US))

Absolutely, from a visual standpoint we are returning to the concept that if you want to have the best at age 30 you have to choose the best at age 21. We did that for many many years but various kinds of pressure were brought to bear. A great deal of money is expended on training an Air Force Academy cadet and large numbers of them actually entered pilot training even though their vision was sub standard compared to previous years.

CARDIOVASCULAR STANDARDS FOR SELECTION AND RETENTION OF HIGH PERFORMANCE PILOTS IN THE USAF: PERSPECTIVES FOR THE NEXT DECADE

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SUMMARY

Cardiovascular selection and retention standards for aircrew involved in the operation of high performance aircraft during the next decade must be based upon a number of considerations which are primarily epidemiological in nature.

SELECTION STANDARDS

Standards for the selection of a 21-year-old applicant for high performance flying (HPF) training must recognize that very few real cardiovascular abnormalities exist in a training age population. The first question then becomes, which cardiovascular abnormalities may be reasonably identified by contemporary diagnostic tools in a training age population? Then, of those disorders which may be detected in a young population by current technology, which disorders are aggravated by rapid onset, high sustained $+G_z$ forces? Further, which diagnostic tools are the most cost effective in screening for these disorders in a young population?

Once selected for training, the focus of cardiovascular standards must then shift to those cardiovascular disorders which are most likely to be present in the middle-aged aviator. If careful selection screening has ruled out structural heart defects prior to training, coronary artery disease represents the overwhelming majority of medical death and disability among aircrew in the industrialized nations. Coronary artery disease remains the leading nontraumatic cause of death among United States Air Force (USAF) aviators. Thus, cardiovascular <u>retention</u> criteria for HPF must focus primarily on coronary disease as the defect <u>most likely</u> to be aggravated by HPF. Further, the presence of coronary artery disease in middle age is in large part determined by the occurrence of classical risk factors. To the extent that risk factors predict disease probability, coronary risk assessment, particularly lipids, is a selection item in young trainees. A summary of selection issues follows.

<u>Issues in Selection of HPF Pilot Trainees by Cardiovascular Tests</u>

1. Which disease processes are present and detectable in a 21-year-old applicant?

2. Which cardiovascular findings may be declared normal variants, but require excessive recurrent medical evaluations for later retention?

3. Which cardiovascular findings may be declared normal variants, but require invasive studies to do so?

4. Which cardiovascular noninvasive tests may be applied to training applicants, and what do they mean?

In the USAF, the predominant cardiovascular abnormalities in a training age population are congenital and valvular lesions such as mitral valve prolapse, aortic valve lesions, undetected atrial and ventricular septal defects, and hypertrophic cardiomyopathies. Beyond these disorders, few other types of cardiovascular abnormalities exist with any frequency in a healthy population. Conduction disturbances and some arrhythmias represent potential cardiovascular disease in a training population. While one would expect to find virtually no anatomic coronary disease in a training age population, lipid patterns predictive of a high risk for the later development of obstructive coronary disease may clearly be detected in 21-year-old applicants. Thus, one finds the following areas which may be reasonably considered as selection items in a training age population:

1. Conduction defects and complex arrhythmias

2. Congenital heart lesions

3. Valvular heart lesions

4. Coronary risk factors

Electrocardiographic Findings

The USAF currently views only a few electrocardiographic (ECG) findings as absolutely unacceptable for all flying training. These findings are as follows:

1. Wolff-Parkinson-White ECG finding

2. Left bundle branch block

3. Complete heart block (not A-V dissociation due to increased vagal tone)

4. Second degree A-V block, Mobitz II

5. Supraventricular tachycardia

6. Ventricular tachycardia

However, the screening of HPF applicants (or applicants for any type of pilot training) with either exercise treadmill or ambulatory electrocardiography must be approached with great caution. With regard to the treadmill, what information does one expect to derive from the use of maximal exercise testing in an applicant population? The Bayesian distribution of abnormal test results in this population of very low disease density dictates that virtually all abnormal ST segment responses will be "false positives." The same Bayesian distribution problem also virtually assures that any abnormal radionuclide study, such as thallium scintigraphy, done in follow-up of this abnormal ST response, will virtually always be a "false positive" also. Thus, one detects little structural disease with stress testing in a training age population. Further, one is assured that the bulk of abnormal tests will be falsely abnormal. In a population of very low disease density, large numbers of falsely abnormal tests lead to further testing, eventually becoming prohibitive in terms of manpower and materiel expenditures. While the stress test may be useful quite independently as a means to precipitate arrhythmias, it must be recognized that no standards exist in a healthy population for exercise-induced arrhythmias. The USAF School of Aerospace Medicine (USAFSAM) studies in exercise-induced arrhythmias have indicated that the true significance of stress arrhythmias depends upon the presence or absence of underlying organic disease, since complex atrial and ventricular arrhythmias may be frequently seen in healthy subjects with no structural lesions. Also, if one finds complex ectopy at exercise in a young person, one is still obliged to search for the presence or absence of underlying heart disease. While blood pressure responses to exercise may identify some persons with hypertensive tendencies, no natural history data exists upon which to declare a given blood pressure response as "normal" or "abnormal." Lastly, one may defend the stress test as simply a functional capacity test. However, this seems a rather expensive method of determining results largely influenced by aerobic conditioning rather than the determination of cardiovascular attributes desirable in HPF.

Ambulatory Electrocardiography

If one applies Holter monitoring to a large population of healthy subjects, a wide variety of arrhythmias will be seen, most of the arrhythmias occurring in those with no organic or structural defect. As in stress testing, standards for these arrhythmias in a healthy population are nonexistent. Not only are remarkable degrees of ectopy found in healthy subjects, the high degree of vagal tone in a population of well-conditioned applicants ensures that bradyarrhythmias and A-V dissociation will occur frequently. And, having found a potential abnormality on Holter, one must now search for organic structural lesions.

The necessity to pursue further evaluation of nonspecific findings from the treadmills and Holters of an applicant population has lead the USAF to discard tests as selection tools which are primarily functional in nature (treadmill, bicycle, Holter). This decision was made because of the poor correlation of "abnormalities" to an anatomic substrate. No norms exist for the wide range of essentially physiological responses to such tests. Therefore, the significance of "abnormal" findings depends upon the presence or absence of organic or structural defects. Findings which appear to fall outside of the usually recognized "normal limits" for a diagnostic test, but in the absence of any underlying organic disease, are termed "normal variants." Intensive testing is virtually always necessary to accurately label a normal variant, and yet underlying organic disease is rarely found in a healthy population. Thus, the USAF is currently considering only the pursuit of structural abnormalities in young HPF applicants.

The Echocardiogram

The echocardiogram is the contemporary noninvasive tool most likely to detect the common structural defects in a training age population. The echocardiogram is noninvasive, gives both anatomic and resting functional data, and detects the majority of aeromedically significant structural lesions such as valvular lesions, missed congenital lesions, and cardiomyopathies. Further, the echocardiogram is an excellent baseline test, for changes in the echocardiogram over time are almost surely due to

acquired disease states. The echocardiogram may also form the basis of an epidemiological study of the cardiovascular effects of repetitive HPF. The USAF is considering the institution of echocardiographic screening (both M-mode and two-dimensional studies) on all HPF candidates as the first step in the construction of a central long-term echocardiographic repository of all HPF pilots. We estimate that the prevalence of abnormal echocardiograms will be 5% in a training population.

Risk Factors

In addition to screening for hypertension, the USAF has added a lipid selection criteria for all flying training. These lipid selection criteria may be summarized as follows:

1. Familial hyperlipidemias are disqualifying for all training.

2. Serum cholesterol of 230 mg/dl necessitates a repeat determination plus HDL measurement (after 14-hour fast).

3. As a working definition, familial hyperlipidemia will be defined for aeromedical screening purposes as a continued serum cholesterol of 250 mg/dl plus one or more of the following:

(a) HDL equal to or less than 15% of total cholesterol.

(b) Total cholesterol greater than 300 mg/dl.

(c) Xanthelasma or xanthomata

(d) First degree family history less than 60 years of age for angina, infarction, or sudden death.

While cigarette smoking is considered a major long-term risk for atherosclerotic disease, obstructive pulmonary disease and cancer, the USAF has not yet restricted flying training to nonsmokers.

Thus, we arrive at the currently envisioned initial noninvasive screening battery for HPF applicants:

Treadmill - No

Holter - No

Scalar ECG - Yes

Lipids - Yes

Echo - Yes

Related Issues

The application of specific tests for high performance applicants raises a number of related issues which bear on the timing of specialized cardiovascular tests such as echocardiography. Should screening by echocardiogram be limited to candidates for high performance systems (operational systems with rapid onset and high sustained G capability?), or, should all applicants for any flying training receive such specialized screening? If one subscribes to the "universally assignable resource" concept, then all pilot applicants must be capable of physical qualification for all conceivable aircraft systems within the organization. Such a selection and training philosophy is depicted in Figure I.

Applicant Pool $\xrightarrow{A}$ Complete Medical Screening $\xrightarrow{B}$ Universally Assignable Applicants

$\xrightarrow{C}$ Pilot Training $\xrightarrow{D}$ "Graduate" Pilots $\xrightarrow{E}$ Training in Specific Aircraft

Figure I

Alternatively, if the training program is designed to identify candidates for type specific weapon systems such as fighter-attack-reconnaissance or tanker-transport-bomber systems early in the training phase, then such a philosophy is depicted in Figure II.

Applicant Pool $\xrightarrow{A}$ Medical Screening For "Undergraduate" Training $\xrightarrow{B}$ "Common" Trainer Aircraft System

$\xrightarrow{C}$ Selection for Specific Aircraft Training $\xrightarrow{D}$ "Graduate" Pilots, Type Specific

Figure II

Under a training approach as in Figure I, echocardiographic studies must be performed at Point "A" before any aviator training occurs. Implicit in this approach is the necessity to declare echocardiographic abnormalities disqualifying for training, and thereby disqualifying for all types of aircraft, thus preserving the "universally assignable resource" concept. However, preliminary data from USAFSAM indicates that the two most common asymptomatic valvular lesions in the aviator population, mitral valve prolapse and isolated aortic insufficiency, are compatible with long-term non-HPF. Mitral valve prolapse and bicuspid aortic valves represent the majority of the valvular abnormalities detected with echocardiographic screening. Currently, neither of these valvular lesions are waiverable for flying training in the USAF, but both are waiverable for continued flying duties if discovered in fully trained operational pilots.

Mitral Prolapse

Mild, incidentally discovered mitral valve prolapse (MVP) with no significant mitral regurgitation, chest pain, stress arrhythmias, or autonomic instability appears to have an excellent prognosis. Of 253 cases of mitral valve prolapse followed serially at USAFSAM, 178 have been waivered for continued flying duties. Of those 75 who were disqualified, the reasons for disqualification are summarized in Table I.

Causes for Disqualification With Mitral Valve Prolapse (N=75)

MVP with arrhythmias	31
MVP with other medical	21
MVP and associated cardiac disease	7
MVP with conduction defects	6
MVP with coronary disease	5
MVP with chest pain	2
MVP only (flying training subjects)	2
Other (non-medical)	1

Table I

For those disqualified due to MVP and associated cardiac disease, the causes are listed in Table II.

MVP and Associated Cardiac Disease (N=7)

Significant mitral regurgitation	1
Aortic root disease/AI	1
Marfan's syndrome	1
Aortic insufficiency	2
Rheumatic heart disease	1
Aortic root disease/no AI	1

Table II

For those disqualified due to arrhythmias, the types of arrhythmias are outlined in Table III.

MVP Arrhythmia Disqualification (N=32)

Ventricular ectopy (Holter)	9
Stress arrhythmias (treadmill)	6
Ventricular tachycardia	6
Supraventricular tachycardia	11

Table III

It is important to note that even with rather stringent criteria for continued flying status, over 70% of these MVP cases could be maintained on flying status. Further, follow-up of these grounded aviators has revealed a natural history free of morbid events. We believe that the diagnosis of MVP is inconsistent with high performance flying duties because of the pathophysiological relationship of ventricular volume and

cavity size to leaflet prolapse. However, many training candidates with asymptomatic prolapse who have no significant mitral regurgitation, no arrhythmias on Holter monitoring or stress testing, and no associated cardiovascular abnormalities are reasonable candidates for training into non-high performance systems. Currently, MVP remains disqualifying for any flying training in the USAF.

Aortic Insufficiency

Mild aortic insufficiency (AI), almost always the result of a congenitally bicuspid valve in otherwise healthy subjects, is compatible with a lengthy flying career. Current USAF policy prohibits the entry of those with mild AI into pilot training. However, the lesion is usually waiverable when discovered in fully trained aviators. Individuals with AI should not be trained in high performance systems because of the possibility of chronic aggravation of the regurgitant lesion by $+G_z$ acceleration. However, USAFSAM natural history studies have indicated that almost all subjects with incidentally discovered mild isolated AI could be expected to finish a full career in tankers-transports-bombers. Currently, AI remains disqualifying for any flying training in the USAF.

Fortunately, mitral prolapse and mild insignificant AI constitute the bulk of the 5% of subjects expected to have echocardiographic abnormalities in a training population. Thus, echocardiographic screening could be expected to reduce the candidate pool by a full 5% in a screening schema which applies the echocardiographic screen at point "A" in Figure I.

However, if echocardiography is applied only to those entering high performance training (point "C" in Figure II), and the majority of those with mild structural abnormalities are allowed to enter non-high performance training, the total applicant pool is reduced by only 1% since the other 4% may be retained in non-HPF. While many cases of prolapse and AI may be suitable for non-high performance training, there are some structural lesions which we feel should remain unacceptable for all flying training:

1. All cardiomyopathies, with or without obstruction
2. Aortic stenosis of any degree
3. Mitral stenosis of any degree
4. More than trivial mitral regurgitation
5. All unoperated congenital lesions
6. Most operated congenital lesions

These nonwaiverable abnormalities comprise the minority of the expected echocardiographic abnormalities in a training population.

Cost Effectiveness of Echocardiographic Screening

It is not possible to assess the cost effectiveness of echocardiographic screening in a general statement. The efficacy of echocardiographic screening and the timing of the evaluation are dependent upon factors unique to each aviation organization. Such factors as available applicant pool size, size of the aviation force, distribution of aircraft types, and early branching into specific aircraft types during training will affect the cost/benefit ratio. One disadvantage of specialized screening at the "branching point" of a "dual track" training system is that a few subjects may be found unsuitable for further training after some funds for training have already been expended. These costs must be weighed against:

1. The costs of removing high performance pilots from the cockpit as fully trained aviators when structural abnormalities are discovered later in the flying career. This cost is a recurrent one if no echocardiographic screening is carried out, as is currently the case in the USAF.

2. The costs of screening all flying training applicants in a "universally assignable resource" scheme.

Use of Invasive Studies in Training Applicants

In the USAF, invasive procedures have been generally reserved for clarification of medical abnormalities in those who are already trained to fly. We feel that the use of invasive procedures with some degree of risk, such as left heart catheterizations, angiography, and electrophysiological studies, should be restricted to trained aviators. We feel that the routine application of procedures with some risk cannot be justified simply to qualify for the opportunity to pursue a hazardous occupation. Many potential candidates for such invasive procedures have not demonstrated any specific aptitudes for aviation duties, and indeed many will not successfully complete the training. Further, many will not pursue military aviation as a career. Under these circumstances, we continue to feel that invasive procedures should not be offered as a result of screening tests in applicants. Current technology is available to potentially elucidate the physiology of Wolff-Parkinson-White ECG finding, Mobitz II second

degree A-V block, supraventricular tachycardia, ventricular tachycardia, and left bundle branch block. We feel that invasive evaluation of these findings in pilot applicants should be highly restricted.

Specialized Tests for Retention in High Performance Duties

Once qualified for HPF duties, and having been found to be free of structural lesions at a training age, the dominant future risk becomes silent coronary artery disease. We feel that the use of routine stress tests in an unstratified fashion for the detection of latent coronary disease should be replaced by recurring risk factor analysis based upon lipids, age, blood pressure, family history, and smoking history. Our future goal is to apply a stratified risk analysis which will determine a threshold for second order tests such as treadmills and scintigraphic studies.

SUMMARY

Figure III outlines a basic cardiovascular selection scheme for a "dual track training" system. Figure IV outlines the projected selection losses. Table IV lists the recommended tests and frequency of testing.

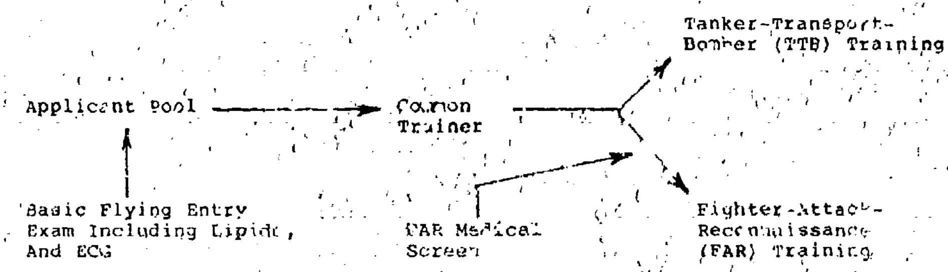

Figure III

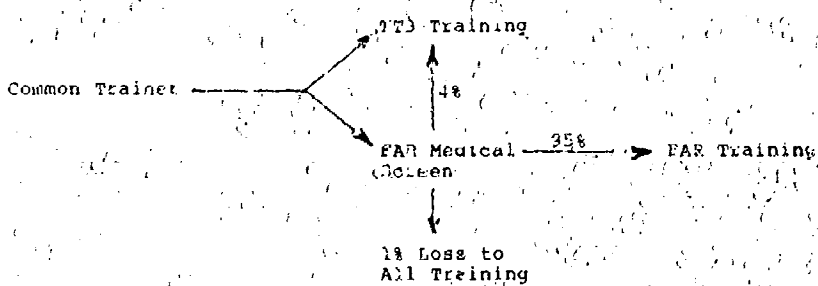

Figure IV

	Pilot Training Entry	FAR Selection	Retention All Flying Categories
Lipids	Yes	Yes	Yes. 25, 30, 35, annually thereafter
Scalar ECG	Yes	Yes	Yes, annually after 35
Treadmill	No	No*	No**
Echo	No	Yes	No
Holter	No	No	No

* For evaluation of echocardiographic abnormalities
** Based upon risk indications

Table IV

CONCLUSIONS

In young applicants for training, there is little rationale in the performance of expensive, labor intensive studies which yield nonspecific results, most of which are normal variants. In our opinion, stress tests and Holter monitors fall into this category. Since the significance of nonspecific findings is determined by the presence or absence of underlying organic structural defects, we recommend that testing in a young population be directed toward the detection of anatomical defects. We recommend that abnormal findings of a structural nature then be assessed with functional tests to determine whether the applicant may enter some form of aviation training or be disqualified from all training.

The opinions expressed in this paper are those of the authors, and do not necessarily represent the opinion of the United States Air Force.

SELECTION ET SURVEILLANCE MEDICALES DES PILOTES DE MIRAGE 2000 : APPORT DE L'ECHOCARDIOGRAPHIE

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RESUME

L'intérêt de l'échocardiographie dans la sélection des équipages des futurs avions de combat est éclairé par une étude comparative de deux populations homogènes de pilotes, l'une, témoin, de 34 pilotes de transport, l'autre de 32 pilotes d'avions de combat. Cette étude montre que l'on trouve dans les deux populations des anomalies du coeur gauche (prolapsus valvulaire mitral de faible degré, isolé, méconnu) mais que des anomalies du coeur droit sous forme d'une dilatation ventriculaire droite sont particulières aux pilotes d'avions de combat. Les auteurs envisagent deux hypothèses : soit une adaptation du coeur droit aux accélérations, soit un stade précoce d'atteinte myocardique secondaire à ces mêmes contraintes aéronautiques.

INTRODUCTION

Comme les autres avions de combat à hautes performances, le Mirage 2000 impose à son pilote des accélérations de haute intensité (+ 9 Gz) soutenues (plus de 15 secondes) et très brutalement installées (1 à 7 Gz par seconde).

L'homme est ainsi amené à l'extrême limite de sa tolerance physiologique et l'on peut redouter la survenue d'incapacités subites en vol.

Bien que les effets sur le système cardiovasculaire des accélérations + Gz soutenues, de haute intensité aient été largement étudiées chez l'animal et chez l'homme volontaire, en centrifugeuse, on ne sait presque rien sur le devenir à long terme des pilotes exposés quotidiennement, pendant des années, à de tels facteurs de charge.

Toute anomalie cardiaque infraclinique, considérée comme minime ou négligeable, est la cause potentielle d'une incapacité subite sous l'effet des accélérations, et elle peut être aggravée à long terme. Ainsi, les caractéristiques nouvelles d'un facteur de charge bien connu amènent à se poser la question de l'opportunité d'une nouvelle définition des normes d'aptitude médicale des pilotes de Mirage 2000.

Dans l'armée de l'air française, la réglementation concernant l'aptitude des pilotes d'avions de combat est simple et rigoureuse.

Lors de la sélection et lors des visites médicales périodiques annuelles, aucune anomalie n'est tolérée. La normalité cardiaque et vasculaire est exigée sur les critères de l'examen clinique, électrocardiographique et radiologique.

Les investigations plus spécialisées ne sont pratiquées qu'à la demande du médecin examinateur.

En ce qui concerne les pilotes désignés pour voler sur Mirage 2000, il a été décidé de ne pas modifier la réglementation en vigueur dans son principe. Mais dans un but d'harmonisation, tous ces pilotes sont examinés dans un même centre et tous doivent subir un examen échocardiographique.

Nous avons renoncé à la pratique systématique de l'électrocardiogramme d'effort, le réservant aux sujets définis comme à haut risque de coronaropathie.

Nous avons également renoncé à l'usage systématique de la centrifugeuse pour des raisons de faisabilité. Par contre la pratique d'un électrocardiogramme de longue durée comportant l'enregistrement durant un vol opérationnel a été retenu.

1. BUT DE L'EXAMEN ECHOCARDIOGRAPHIQUE

Le but de l'introduction de l'échocardiographie dans le protocole d'examen standard des pilotes de Mirage 2000 était :

- d'éliminer certains pilotes porteurs d'anomalies cardiaques mineures, infracliniques mais source de danger sous facteurs de charge ;

- de recueillir des informations objectives, comparables dans une étude prospective, sur les conséquences cardiaques et vasculaires éventuelles de l'exposition répétée des pilotes aux accélérations, à moyen et à long terme ;

- d'établir une doctrine rationnelle sur l'opportunité de définir des normes nouvelles d'aptitude médicale pour les pilotes des avions de combat de la nouvelle et future génération.

2. MATERIEL ET METHODOLOGIE

2.1. APPAREILLAGE

L'examen échocardiographique a été réalisé avec un appareil sectoriel à balayage mécanique ATL Mark 500 comportant une sonde de 3 MHz. L'étude du coeur est conduite selon un protocole standardisé (incidence parasternale, coupe grand axe et petit axe, incidence apexienne, incidence sous costale). Les examens en mode T.M. ont été pratiqués, à partir de l'examen bidimensionnel pour permettre la meilleure incidence et le choix du faisceau T.M. le plus perpendiculaire aux structures cardiaques. L'imagerie bidimensionnelle est enregistrée sur bande vidéo, les documents T.M. sur papier photographiques à sec. L'examen est complété à la demande par une étude des flux intracardiaques par Doppler pulsé.

2.2.1. 32 PILOTES DE CHASSE confirmés sur Mirage III, Mirage F1 que nous appellerons indifféremment "pilotes de chasse ou pilotes Mirage 2000 " ont subi une échocardiographie pendant leur visite médicale de qualification sur Mirage 2000. L'examen échocardiographique a été aussi pratiqué sur une population témoin de 34 PILOTES DE TRANSPORT ou de LIAISON, d'âge équivalent.

2.2.2. L'ACQUISITION DES DONNEES (tableaux I et II en annexe) concerne :

2.2.2.1. DES PARAMETRES ANTHROPOMETRIQUES : âge, poids, taille, surface corporelle, exprimées en unités habituelles auxquelles nous avons ajouté une caractéristique professionnelle : le nombre d'heures de vol de chacun des individus.

2.2.2.2. DES PARAMETRES ECHOGRAPHIQUES EN MODE T.M. par les :

a) Mesures exprimées en millimètres des épaisseurs de parois ou des diamètres des cavités cardiaques prises suivant les modalités décrites antérieurement,

Diamètre de l'oreillette gauche (OG)
Diamètre du ventricule droit (VD)
Diamètre diastolique (Dd) du ventricule gauche (VG)
Diamètre systolique (Ds) du ventricule gauche

Epaisseur en diastole (Ed) du septum (Sep)
Epaisseur en systole (Es) du septum
Epaisseur en diastole de la paroi postérieure (PPo)
Epaisseur en systole de la paroi postérieure

b) Valeurs, exprimées en pourcentage

- du raccourcissement systolique du diamètre VG (% Racc VG)
- de l'épaississement systolique du septum (% ép sep)
- de l'épaississement systolique de la paroi postérieure. (% ép PPo)

2.2.2.3. DES ASPECTS MORPHOLOGIQUES EN ECHOCARDIOGRAPHIE BIDIMENSIONNELLE et des résultats de l'examen Doppler pulsé.

3. RESULTATS : Voir tableaux 1 et 2 en annexes.

3.1. EN MODE T.M. MOYENNES DES PARAMETRES ECHOCARDIOGRAPHIQUES PRECEDEMMENT DEFINIS

	OG	VD	VG Dd	VG Ds	Sep Ed	Sep Es	PPo Ed	PPo Es
TEMOINS	32.353	13.265	48.500	31.294	7.265	11.344	7.147	11.719
P.CHASSE	30.813	16.750	49.219	31.250	7.438	12.094	6.938	12.000

	% Racc. VG	% ep. Sep	% ep. PPo
TEMOINS	35.741	60.683	70.985
P.CHASSE	36.211	66.706	75.698

T A B L E A U 3

3.2. EN BIDIMENSIONNEL, L'échographie bidimensionnelle couplée au Doppler pulsé permet de définir :

3.2.1. PARMI LES PILOTES DE CHASSE

- un groupe de 20 sujets classés comme rigoureusement normaux ;
- un groupe de 12 sujets présentant une anomalie.

Dans 4 cas, cette anomalie intéresse l'appareil mitral avec en systole un mouvement vers l'OG de l'un ou des deux feuillets mitraux, le point de coaptation des deux feuillets se situant toujours, sur les différentes coupes dans le plan de l'anneau mitral. Ces aspects correspondent aux plus faibles degrés de prolapsus valvulaire mitral.

Dans 8 cas, l'anomalie porte sur le ventricule droit avec un certain degré de dilatation ventriculaire droite.

Le diamètre moyen du VD dans ce groupe (Pilotes anom. ventr. D) est de 22,500 mm. Dans l'une des observations de ce groupe, le Doppler pulsé met en évidence une insuffisance tricuspidienne.

3.2.2. PARMI LES TEMOINS

- un groupe de 30 sujets classés comme normaux ;
- un groupe de 4 sujets présentait une anomalie : 3 sujets avaient les signes d'un faible degré de prolapsus valvulaire mitral, 1 seul avait une dilatation ventriculaire droite isolée.

4. TRAITEMENT DES DONNEES

Le traitement des données s'établit à deux niveaux d'analyse :

- homogénéité des populations,
- caractérisation échocardiographique des individus.

4.1. L'HOMOGENEITE DES POPULATIONS EST ETUDIEE A L'AIDE DE 4 TESTS STATISTIQUES SIMPLES

4.1.1. CALCUL DES MOYENNES ET DES ECARTS TYPES

- de chacune des populations,
- de l'ensemble des sujets sur chacun des paramètres anthropométriques.

4.1.2. ANALYSE DE VARIANCE A UN CRITERE SUR CHACUN DES PARAMETRES PRECEDENTS

En raison du mode de choix des individus les tests seront effectués au niveau le plus haut de significativité (1 %).

4.1.3. UNE ANALYSE EN COMPOSANTES PRINCIPALES SUR L'ENSEMBLE DE LA POPULATION, dans l'espace des variables et l'espace des individus (nombre de vecteurs de la base = cinq).

4.1.4. UNE ANALYSE EN COMPOSANTES PRINCIPALES DANS L'ESPACE DES VARIABLES ET DES INDIVIDUS DE LA POPULATION DE PILOTES DE MIRAGE 2000 (nombre de vecteurs de la base de l'hyperespace vectoriel = cinq).

4.2. CARACTERISATION STATISTIQUE ECHOCARDIOGRAPHIQUE

La caractérisation statistique échocardiographique des sujets procède de la même approche.

4.2.1. CALCUL DES MOYENNES ET DES ECARTS TYPES DES VARIABLES ECHOGRAPHIQUES PORTANT SUR QUATRE POPULATIONS

- l'ensemble des pilotes Mirage 2000,
- le population témoin,
- l'ensemble des deux précédentes populations,
- un groupe de 8 sujets (pilotes anom. Ventric. D), qui ne constitue évidemment pas une population statistique, mais pour lesquels une anomalie qui sera discutée ultérieurement a été remarquée.

4.2.2. UNE ANALYSE EN COMPOSANTES PRINCIPALES PORTANT SUR LA POPULATION GLOBALE DANS LES DEUX ESPACES DES VARIABLES ET DES INDIVIDUS. NOMBRE DE VECTEURS DE L'ESPACE DES VARIABLES : 11.

Le calcul des valeurs relatives, exprimées en pourcentage des variables, nécessite l'obtention de distances obtenues par des mesures effectuées en systole et en diastole : ces valeurs ont été ajoutées au tableau des données (en annexe) bien qu'elles n'apportent pas de degré de liberté supplémentaire. Cependant, bien qu'il n'existe aucune justification mathématique de l'augmentation de taille du tableau des données, il nous a semblé utile de vérifier si les deux variables Ed et Es du Septum sont bien correlées avant de les utiliser dans le calcul d'une grandeur ayant éventuellement une valeur diagnostique.

5. RESULTATS STATISTIQUES

5.1. LES MOYENNES ET LES ECARTS TYPES DES VARIABLES ANTHROPOMETRIQUES SONT DONNES DANS LE TABLEAU SUIVANT :

	TEMOINS		PILOTES		TOTAL	
	Moyenne	Ecart type	Moyenne	Ecart type	Moyenne	Ecart type
AGE	31.000	3.175	30.188	4.112	30.606	3.685
POIDS	70,471	6.486	72.688	7.437	71.545	7.058
TAILLE	176.000	6.088	176.563	5.663	176.273	5.900
SURFACE CORPORELLE	1.872	0,153	1.904	0.167	1.888	0.161
HEURES DE VOL	2339.59	1610.43	1844.88	919.22	2092.23	1334.19

TABLEAU 4 : Paramètres statistiques des variables anthropométriques étudiées : les paramètres témoignent de la dispersion des populations au plan de la qualification professionnelle.

5.2. LES ANALYSES DE VARIANCE PRATIQUEES SUR LES DEUX POPULATIONS donnent les résultats suivants pour la variable F située entre F_1 ; 63 et F_1 ; 65 (cf. tableaux 1 et 2 en annexe pour les valeurs manquantes).

Age : 0,787
Poids : 1,617
Taille : 0,146
Surface corporelle : 0,641
Heures de vol : 2,207

Les valeurs critiques de la distribution de la variable de Fisher pour les niveaux de 1 % sont :

Prob F (1;60) > 7,08 = 0,01
Prob F (1;70) > 7,01 = 0,01

5.3. La visualisation de ces résultats est apportée par l'analyse en composantes principales dans laquelle il convient de noter que le tableau des valeurs propres accolé au tracé du cercle de corrélation est le tableau correspondant aux composantes principales obtenues dans l'espace des individus (graphe N° 1 et N° 2, en annexe). Pour la population des Mirage 2000, les résultats sont visualisés sur les graphiques N° 3 et N° 4.

5.4. Les moyennes et écarts-types des variables ECHOCARDIOGRAPHIQUES sont données dans le tableau 5.

5.5. Les analyses de variance pratiquées sur les deux populations donnent les résultats suivants pour la variable F telle que F_1 ; 65 (cf. tableau 1 et 2 en annexe pour les valeurs manquantes).

OG = 4,127
VD = 8,265
VGDd = 0,577
VGDs = 0,002
% Racc = 0,266
Septum Ed = 0,224
Septum Es = 4,585
% Epaiss. septum = 0,866
PPo Ed = 0,385
PPo Es = 2,568
% Epaiss. PPo = 0,620

Les valeurs critiques de la distribution de la variable de Fisher pour les niveaux de 1 % et de 5 % sont :

Prob F (1;60) > 7,08 = 0,01
Prob F (1;70) > 7,01 = 0,01
Prob F (1;60) > 4,00 = 0,05
Prob F (1;70) > 3,98 = 0,05

	TEMOINS		PILOTES total		PILOTES anom. ventr. D		TOTAL	
	MOYENNE	ECART type	MOYENNE	ECART type	MOYENNE	ECART type	MOYENNE	ECART type
OG	32.353	3.125	30.813	2.929	30.125	2.711	31.606	3.125
VD	13.265	4.157	16.750	5.480	22.500	6.330	14.955	5.151
VG Dd	48.500	3.338	49.219	4.202	51.000	3.608	48.848	3.794
VG Ds	31.294	3.204	31.250	3.384	33.375	2.824	31.273	3.291
% Racc	35.741	3.300	36.211	3.971	34.656	3.520	35.969	3.651
Sept. Ed	7.265	1.379	7.438	1.537	7.875	1.054	7.348	1.459
Sept. Es	11.344	1.993	12.094	1.701	12.125	1.364	11.719	1.889
% ep Sep	60.683	23.088	66.706	27.588	56.647	26.326	63.694	25.634
PPost Ed	7.147	1.330	6.938	1.367	7.375	1.577	7.045	1.353
PPost Es	11.719	1.094	12.000	1.678	12.000	0.857	11.859	1.421
% ep PPo	70.985	27.075	75.698	19.456	68.075	26.098	73.341	23.687

T A B L E A U 5

5.6. La visualisation de la projection du nuage de points individus sur le meilleur plan de dispersion est donné par le graphe n° 5 tandis que la projection des points variables dans le plan du cercle de corrélation est donnée par le graphe n° 6, le graphe n° 7 concerne les pilotes ayant une anomalie ventriculaire droite.

6. INTERPRETATION STATISTIQUE

L'analyse de variance pratiquée sur les données ANTHROPOMETRIQUES et le caractère professionnel ne permet pas de rejeter l'hypothèse nulle ; elle indique donc que les populations ne sont pas statisquement différentes pour les caractères étudiés.

Dans ces deux populations, poids, taille, et surface corporelle sont parfaitement correlées ; mais la corrélation entre âge et le nombre de vols est nulle, ces deux variables indiquant que plus un sujet est âgé, plus il a l'expérience du pilotage. Ces données qui ne sont pas novatrices ont l'avantage de montrer la validité des calculs. Le graphique n° 2 montre bien l'homogénéité des populations qui se placent dans une hyperellipsoïde proche d'une hypersphère ; la population de Mirage 2000 est certainement un peu moins homogène en ce qui concerne l'âge, le poids, le nombre d'heures de vol.

Les valeurs des principales mesures ECHOCARDIOGRAPHIQUES sont rapportées au tableau 5. Comparées aux données habituelles de la littérature (HENRY W.L., GARDIN J.M. ou FEIGENBAUM H.), les écarts types de nos résultats sont meilleurs : il convient de préciser que notre population pour homogène qu'elle soit, est une population d'adultes mâles par définition en excellente santé. On ne s'étonnera donc pas de trouver aussi, des valeurs d'épaisseur des parois du muscle cardiaque supérieures dans notre population évidemment plus sportive que la moyenne de la population des deux sexes. En ce qui concerne l'analyse de variance à un critère portant sur chacun des éléments échographiques, on constate :

- qu'il n'existe pas de différence statistiquement significative entre les populations "Mirage 2000" et les témoins pour les dimensions du Dd et Ds du VG, Ed du Septum, Ed et Es de la PPo, pourcentage d'épaississement de la P.Post ;

- qu'il existe une différence significative (au niveau de 5 %) des dimensions de l'oreillette gauche et de l'épaisseur du septum en systole ;

- qu'il existe enfin une différence HAUTEMENT SIGNIFICATIVE sur les dimensions du VD.

Si l'on se reporte au tableau n° 5, il apparaît clairement que cette différence est le fait des 8 personnes pour lesquelles il a été demandé une étude particulière (Pilotes - anomalies - Ventric. droite). Leur moyenne VD est en effet égale à 169 % de la moyenne de la population témoin, avec un écart type un peu supérieur à 2 mm. Si l'on retire ces 8 individus de la population totale des pilotes de Mirage 2000, il n'existe plus de différence apparaissant entre les deux populations mais la validité du test statistique est elle-même diminuée d'autant !

L'examen de la situation des nuages de points sur le meilleur plan de projection montre approximativement que sur l'ensemble des variables échocardiographiques les 2 populations restent homogènes (graphe n° 5) et que les huit sujets qui sont responsables de la différence précédemment citée, sont harmonieusement distribués par rapport au centre de gravité de la projection des points individus. Reste le délicat problème de l'interprétation de la projection des points variables sur le cercle des conclations : il n'est pas possible d'admettre que les épaisseurs du septum en diastole et en systole sont deux paramètres correlés (l'acquisition de leurs dimensions pose -au plan purement géométrique- un problème. En effet, les mesures sont relevées sur une projection curvilinéaire (la paroi thoracique) d'un élément cardiaque EN MOUVEMENT et qui de plus, a grossièrement la forme d'une calotte sphérique). De même, ne sont pas correlés les paramètres représentés par l'épaississement de la paroi postérieure aux deux pôles du cycle cardiaque.

Par contre, les dimensions du VG en systole et en diastole sont bien correlées ce qui signifie que il existe une relation commune entre le sens des variations des Dd et des Ds du VG chez tous les individus, autrement dit les variables Dd VG et Ds VG sont parfaitement correlées.

7. COMMENTAIRES

L'étude échocardiographique et l'analyse statistique qui en a été faite font apparaître les points suivants :

- la découverte d'anomalies mineures de la valve mitrale, tout à fait méconnues, aussi bien dans la population des pilotes de chasse que dans la population témoin. La détection de ces anomalies susceptibles d'aggravation sous l'influence de facteurs de charge justifient la pratique de l'examen au début de la formation sur Mirage 2000 et la surveillance régulière même si la décision immédiate d'aptitude n'est pas modifiée.

- L'existence d'anomalies ventriculaires droites significativement plus fréquentes dans la population des pilotes de chasse posent le problème de leur signification. La comparaison avec une population homogène de pilotes d'une autre spécialité fait envisager pour les pilotes de chasse l'intervention d'un facteur particulier aux avions de combat à savoir les accélérations. Ces augmentations de dimensions du ventricule droit peuvent traduire une simple adaptation du coeur droit aux contraintes aéronautiques, mais elles peuvent aussi traduire un stade précoce d'atteinte myocardique. Il est actuellement impossible de trancher entre ces deux hypothèses. Seule une surveillance rigoureuse des sujets et une confrontation de nos résultats à ceux de travaux similaires pourront avec le temps y apporter des éléments de réponse.

- Parmi les paramètres de surveillance échocardiographique, le pourcentage de raccourcissement du diamètre qui est un bon reflet de la fonction ventriculaire gauche nous paraît devoir être retenu pour une surveillance à long terme. Nous avons montré sa validité par opposition à d'autres paramètres étudiés comme le pourcentage d'épaississement du septum ou de la paroi postérieure.

8. APTITUDE

Tous les pilotes sauf le sujet porteur d'une insuffisance tricuspidienne ont conservé leur aptitude : on considère que les anomalies constatées entrent dans le cadre d'une "pathologie frontière" que l'on ne sait actuellement situer avec exactitude.

CONCLUSION

Le souci de préserver la sécurité des vols face à des contraintes nouvelles et la disponibilité des techniques actuelles d'investigation non sanglantes amènent à découvrir toujours plus de cas de "pathologie frontière".

Pour éviter de verser dans un excès de prudence aboutissant très vite à l'inefficacité et pour éviter à l'inverse l'excès d'optimisme, il est nécessaire de procéder à l'analyse critique du risque encouru et de la valeur des méthodes de diagnotic ; à cet égard, l'échocardiographie nous apporte les avantages de la fiabilité, de la facilité d'exécution et d'un surcroît d'information. Nous espérons avoir démontré l'intérêt de son inclusion systématique dans les protocoles de sélection des équipages des futurs avions de combat.

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REMERCIEMENTS :

Nous remercions le Médecin en Chef QUANDIEU, Maître de Recherches du Service de Santé des Armées a qui nous devons l'analyse statistique de ce travail,

ANNEXE 1
TABLEAU 1

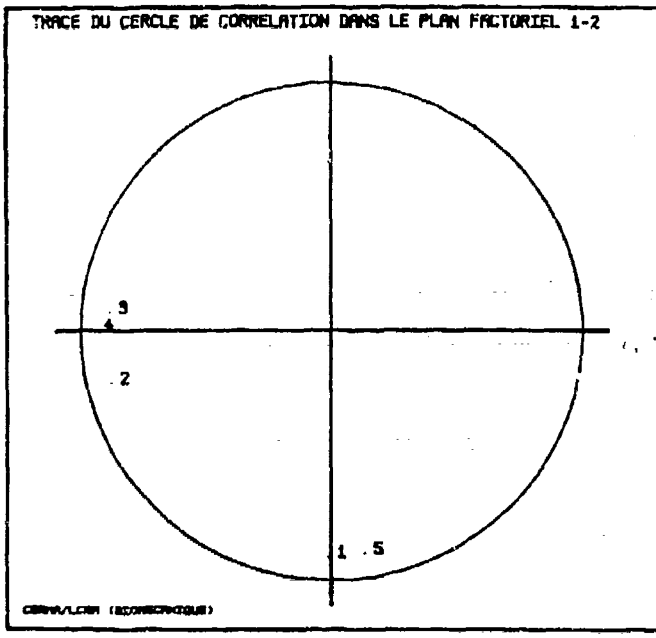
N°	Heures de vol	Age	Poids	Taille	S.Cor	OG	VD	VG.Dd	VG.Ds	% racc	Sep Ed	Sep Es	% Ep Sep	P.Po Ed	P.Po Es	% Ep P.Po	C. droit
1	3100	36	79	173	1.92	29.0	36.0	46.0	30.0	35.0	9.0	12.0	33.3	9.0	13.0	44.4	Anormal
2	1080	28	63	174	1.76	30.0	16.0	51.0	32.0	37.0	6.0	11.0	83.3	9.0	12.0	33.3	
3	1300	29	79	190	2.60	31.0	20.0	52.0	33.0	36.5	9.0	15.0	66.7	6.0	12.0	100.0	
4	1750	27	70	174	1.84	36.0	26.0	56.0	38.0	32.0	9.0	11.0	22.8	10.0	12.0	20.0	Anormal
5	2480	31	74	173	1.86	32.0	15.0	52.0	32.0	38.0	7.0	12.0	71.4	7.0	14.0	100.0	
6	1300	28	74	173	1.86	32.0	17.0	44.0	29.0	34.0	7.0	11.0	57.1	7.0	13.0	85.7	
7	2300	32	64	170	1.74	30.0	16.0	40.0	26.0	35.0	7.0	11.0	57.1	5.0	9.0	80.0	
8	1730	27	68	172	1.80	31.0	26.0	53.0	33.0	40.0	9.0	12.0	33.3	9.0	13.0	44.4	Anormal
9	1400	28	66	178	1.82	28.0	15.0	54.0	37.0	31.0	6.0	12.0	100.0	6.0	12.0	100.0	Anormal
10	3400	36	66	173	1.79	30.0	16.0	44.0	26.0	40.0	11.0	15.0	36.4	8.0	15.0	87.5	
11	2500	36	77	177	1.94	30.0	12.0	52.0	33.0	36.0	10.0	15.0	50.0	10.0	16.0	60.0	
12	1130	30	72	180	1.91	30.0	20.0	54.0	36.0	33.0	6.0	10.0	66.7	6.0	11.0	83.3	
13	3550	34	68	171	1.80	32.0	17.0	51.0	29.0	43.0	10.0	14.0	40.0	8.0	14.0	75.0	
14	2200	30	78	183	2.00	20.0	12.0	44.0	30.0	31.0	6.0	10.0	66.7	7.0	11.0	57.1	
15	3500	40	86	183	2.08	28.0	16.0	50.0	35.0	30.0	7.0	10.0	42.9	6.0	11.0	83.3	Anormal
16	3500	38	67	174	1.80	27.0	20.0	45.0	30.0	33.0	8.0	13.0	62.5	6.0	11.0	83.3	Anormal
17	2670	35	76	180	1.95	36.0	11.0	48.0	25.0	40.0	9.0	12.0	33.3	6.0	9.0	50.0	
18	2000	29	85	190	2.13	30.0	15.0	51.0	30.0	41.0	7.0	13.0	85.7	7.0	13.0	85.7	
19	1100	27	69	170	1.80	32.0	21.0	53.0	32.0	39.0	8.0	15.0	87.5	6.0	11.0	83.3	Anormal
20	1000	27	60	177	1.75	30.0	20.0	51.0	32.0	37.5	7.0	12.0	71.4	7.0	13.0	85.7	Anormal
21	550	25	84	185	2.09	30.0	14.0	49.0	27.0	44.0	8.0	14.0	75.0	8.0	14.0	75.0	
22	500	25	67	180	1.85	30.0	13.0	51.0	34.0	33.0	8.0	12.0	50.0	7.0	12.0	71.4	
23	2600	32	73	174	1.87	35.0	7.0	53.0	30.0	43.0	9.0	13.0	44.4	7.0	13.0	85.7	
24	2000	33	70	179	1.89	30.0	19.0	50.0	28.0	44.0	7.0	15.0	114.3	6.0	11.0	83.3	
25	1000	28	80	178	1.98	32.0	15.0	50.0	32.0	36.0	7.0	13.0	85.7	5.0	9.0	80.0	
26	800	26	73	175	1.88	36.0	10.0	47.0	31.0	34.0	5.0	12.0	140.0	7.0	12.0	71.4	
27	1000	29	79	185	2.03	31.0	14.0	46.0	29.0	36.0	6.0	9.0	50.0	6.0	11.0	83.3	
28	2300	34	91	176	2.08	32.0	17.0	43.0	28.0	34.0	5.0	10.0	100.0	5.0	10.0	100.0	
29	700	24	66	174	1.79	31.0	16.0	46.0	30.0	34.0	8.0	11.0	37.5	7.0	12.0	71.4	
30	2196	29	71	174	1.85	31.0	21.0	46.0	29.0	36.0	6.0	10.0	66.7	8.0	14.0	75.0	
31	700	24	70	169	1.80	30.0	9.0	57.0	38.0	33.0	6.0	11.0	83.3	6.0	11.0	83.3	
32	1700	29	61	166	1.68	34.0	16.0	52.0	36.0	30.0	5.0	11.0	120.0	5.0	10.0	100.0	

A N N E X E 2

T A B L E A U 2

N°	Heures de vol	Age	Poids	Taille	S Cor	OG	VD	VG Dd	VG Ds	% racc	Sep Ed	Sep Es	% Ep. Sep	P.Po Ed	P.Po Es	% Ep P.Po
1	840	34	66	169	1.75	35.0	16.0	46.0	31.0	33.0	10.0	12.0	20.0	9.0	13.0	44.4
2	3400	32	76	176	1.92	29.5	10.0	44.0	26.0	40.0	6.0	11.0	83.3	7.0	12.0	71.4
3	337	30	61	157	1.68	30.0	13.0	51.0	32.0	37.0	6.0	11.0	83.3	6.0	10.0	66.7
4	3200	29	70	177	1.86	34.0	11.0	50.0	32.0	36.0	7.0	11.0	57.1	8.0	12.0	50.0
5	2500	30	71	175	1.86	34.0	8.0	50.0	34.0	32.0	8.0	12.0	50.0	8.0	14.0	75.0
6	1330	26	79	184	2.10	35.0	12.0	53.0	35.0	34.0	6.0	9.0	50.0	7.0	12.0	71.4
7	2200	30	58	168	1.68	25.0	11.0	45.0	29.0	36.0	6.0	9.0	50.0	7.0	11.0	57.1
8	3050	30	79	175	1.95	33.0	16.0	42.0	26.0	38.0	8.0	15.0	87.5	6.0	12.0	100.0
9	340	26	64	182	1.83	30.0	11.0	45.0	27.0	40.0	8.0	10.0	25.0	8.0	13.0	62.5
10	766	32	61	173	1.73	33.0	15.0	51.0	30.0	41.0	8.0	13.0	62.5	6.0	11.0	83.3
11	2200	31	79	175	1.95	34.0	22.0	52.0	36.0	31.0	7.0	11.0	57.1	6.0	12.0	100.0
12	3100	29	69	173	1.51	31.0	12.0	52.0	36.0	31.0	6.0	11.0	83.3	6.0	11.0	83.3
13	1060	34	80	180	2.00	38.0	14.0	49.0	32.0	35.0	9.0	12.0	33.3	9.0	12.0	33.3
14	150	28	82	185	2.50	35.0	14.0	52.0	35.0	33.0	7.0	13.0	85.7	9.0	12.0	33.3
15	4500	35	72	178	1.88	34.0	11.0	49.0	33.0	33.0	8.0	11.0	37.5	8.0	13.0	62.5
16	260	31	79	177	1.96	36.0	7.0	45.0	28.0	38.0	6.0	10.0	66.7	6.0	11.0	83.3
17	1200	29	76	186	1.96	32.0	11.0	44.0	30.0	32.0	9.0	14.0	55.6	6.0	13.0	116.7
18	1000	23	61	171	1.71	26.0	8.0	49.0	32.0	35.0	6.0	12.0	100.0	6.0	10.0	66.7
19	2100	34	73	181	1.94	34.0	15.0	55.0	37.0	33.0	6.0	10.0	66.7	9.0	12.0	33.3
20	877	88	69	174	1.83	31.0	14.0	45.0	29.0	36.0	6.0	11.0	83.3	6.0	11.0	83.3
21	1450	33	66	168	1.75	37.0	12.0	49.0	30.0	38.7	7.0	10.0	42.9	7.0	11.0	57.1
22	3100	34	74	181	1.95	32.0	11.0	48.0	30.0	37.5	7.0	12.0	71.4	6.0	11.0	83.3
23	5305	34	75	182	1.95	36.0	9.0	50.0	38.0	34.0	7.0	10.0	42.9	8.0	12.0	50.0
24	3700	31	73	180	1.92	33.0	12.0	55.0	34.0	33.0	6.0	10.0	66.7	9.0	13.0	44.4
25	3580	30	75	177	1.90	37.0	10.0	52.0	36.0	31.0	5.0	5.0	0.0	6.0	9.0	50.0
26	1650	32	69	178	1.80	31.0	11.0	45.0	26.0	42.0	6.0	12.0	100.0	7.0	12.0	71.4
27	1251	31	74	189	2.00	31.0	21.0	46.0	30.0	35.0	10.0	15.0	50.0	8.0	10.0	25.0
28	3700	30	62	172	1.74	31.0	13.0	45.0	31.0	32.0	8.0	14.0	75.0	6.0	11.0	83.3
29	1750	31	74	178	1.91	30.0	10.0	45.0	30.0	33.0	8.0	14.0	75.0	7.0	13.0	85.7
30	3060	37	68	179	1.86	28.0	17.0	50.0	31.0	38.0	8.0	13.0	62.5	6.0	11.0	83.3
31	5100	36	64	160	1.67	30.0	18.0	45.0	27.0	40.0	9.0	-1.0	-1.0	8.0	-1.0	-1.0
32	-1	33	66	170	1.76	36.0	25.0	50.0	31.0	38.0	10.0	-1.0	-1.0	11.0	-1.0	-1.0
33	6811	36	71	175	1.86	34.0	21.0	51.0	29.0	43.0	8.0	11.0	37.5	6.0	12.0	100.0
34	-1	25	60	169	1.69	27.0	10.0	49.0	31.0	36.0	5.0	9.0	80.0	5.0	13.0	160.0

A N N E X E 3



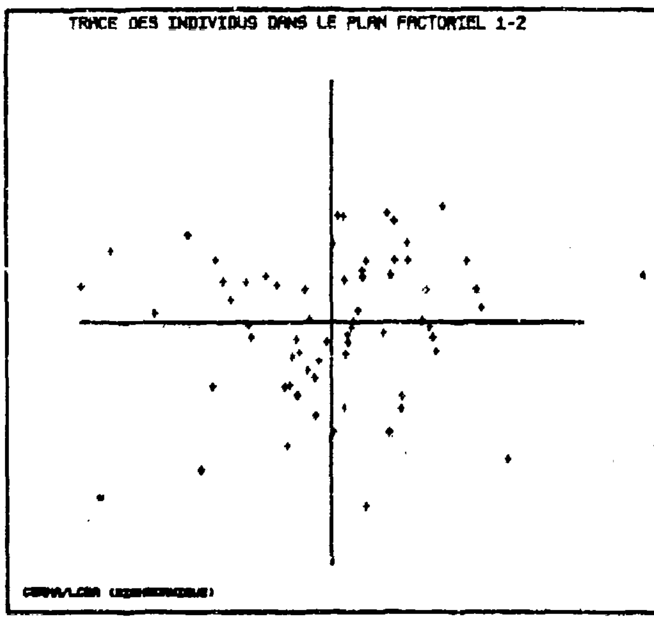
CORRESPONDANCE INDICES-CARACTERES

1 = Age
2 = Poids
3 = Taille
4 = Surface corporelle
5 = Nbre heures de vol

Graphe n° 1

Fichier : DKO:MIRAS.DAT

Val. Propres	% Inertie	Cumul
2.460	49.2%	49.2%
1.670	33.4%	82.6%
0.387	7.3%	89.9%
0.334	6.6%	96.6%



CORRESPONDANCE COULEURS-INDIVIDUS
Bleu : Popul. de reference
Rouge : Pilotes MIRAGE 2000

Fichier : DKO:MIRAS.DAT

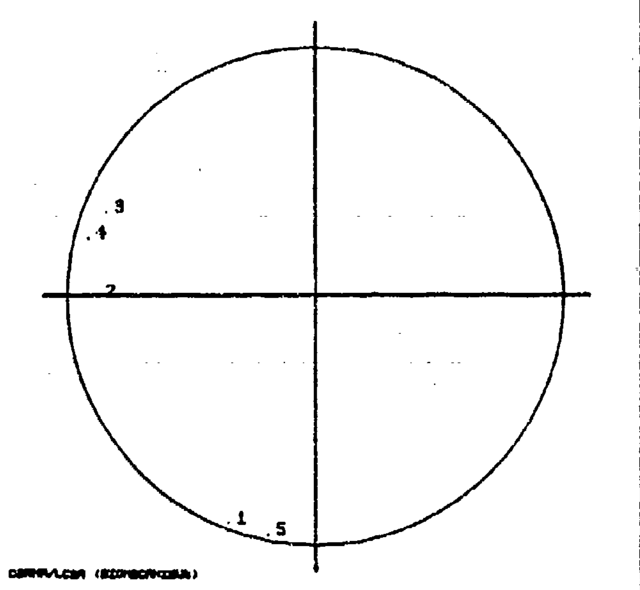
LISTE DES CARACTERES ETUDIES

Age
Poids
Taille
Surface corporelle
Nbre heures de vol

Graphe n° 2

A N N E X E 4

TRACE DU CERCLE DE CORRELATION DANS LE PLAN FACTORIEL 1-2



CORRESPONDANCE INDICES-CARACTERES

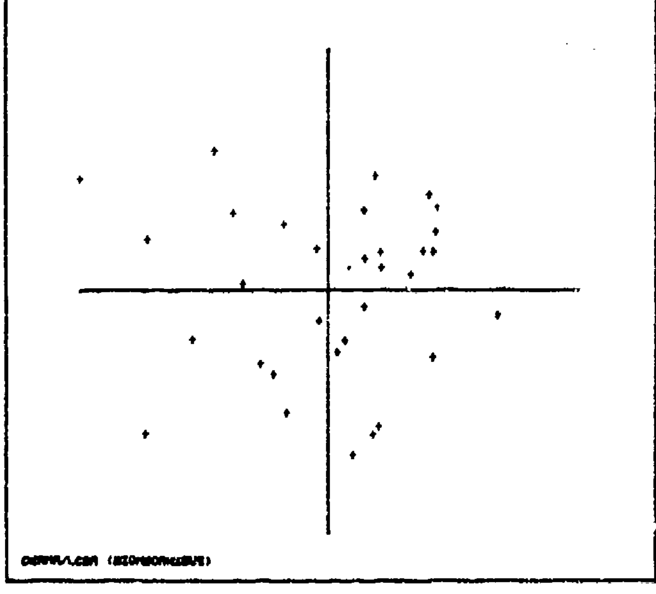
1 = Age
2 = Poids
3 = Taille
4 = Surface corporelle
5 = Nbre heures de vol

Graphe n° 3

Fichier : DKO:MIRA2.DAT

Val. Propre	% Inertie	Cumul
2.484	49.7%	49.7%
1.921	38.4%	88.1%
0.353	7.0%	95.1%
0.163	3.2%	98.4%

TRACE DES INDIVIDUS DANS LE PLAN FACTORIEL 1-2



CORRESPONDANCE COULEURS-INDIVIDUS
Rouge : Pilotes MIRAGE 2000

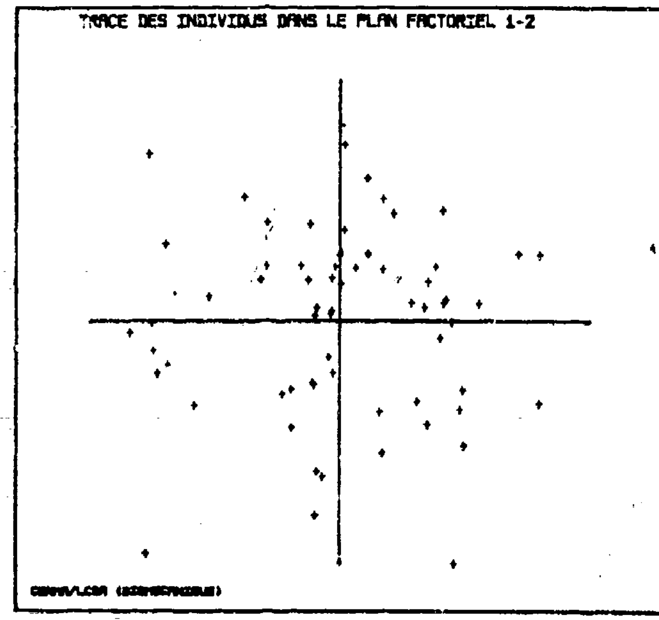
Fichier : DKO:MIRA2.DAT

LISTE DES CARACTERES ETUDIES

Age
Poids
Taille
Surface corporelle
Nbre heures de vol

Graphe n° 4

A N N E X E 5



CORRESPONDANCE COULEURS-INDIVIDUS

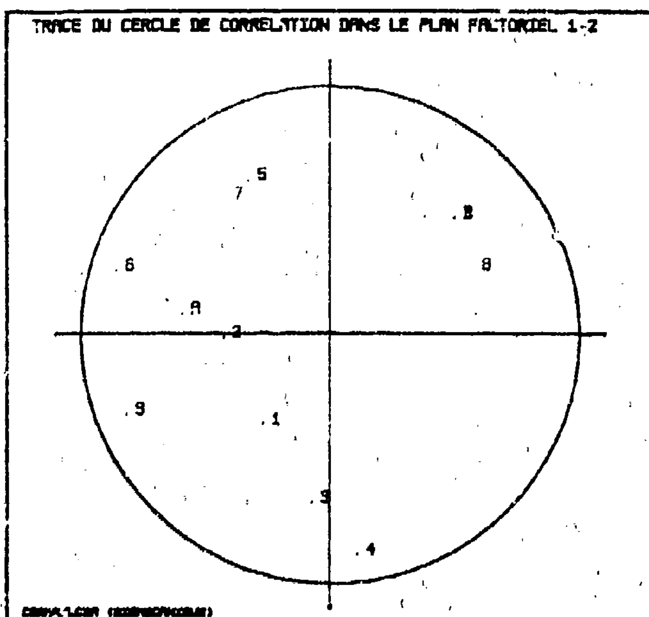
Bleu : Popul. de reference
Rouge : Pilotes MIRAGE 2000

Fichier : MIRA4.DAT

LISTE DES CARACTERES ETUDIES

- Oreillette gauche
- Ventricule droit
- V.G. diastolique
- V.G. systolique
- V.G. % raccourcies.
- Septum epais. Diast.
- Septum epais. Syst.
- Septum % epais.
- P.Post. epais. Dias.
- P.Post. epais. Syst.
- P.Post. % epais.

Graphe n° 5



CORRESPONDANCE INDICES-CARACTERES

1 = Oreillette gauche
2 = Ventricule droit
3 = V.G. diastolique
4 = V.G. systolique
5 = V.G. % raccourcies.
6 = Septum epais. Diast.
7 = [illegible]
8 = Septum % epais.
9 = P.Post. epais. Dias.
A = P.Post. epais. Syst.
B = P.Post. % epais.

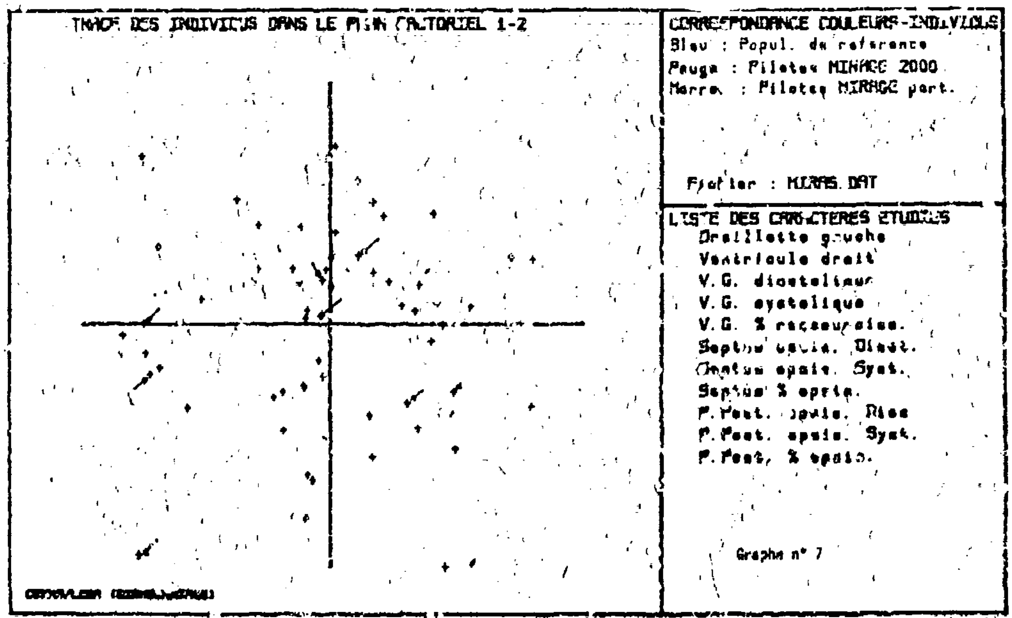
Graphe n° 6

Fichier : MIRA4.DAT

Espace des individus :

Val. Propres	% Inertie	Cumul
2.876	26.1%	26.1%
2.522	22.9%	49.1%
1.421	12.9%	62.0%
1.052	9.5%	71.6%

ANNEXE 6


TRACE DES INDIVIDUS DANS LE PLAN FACTORIEL 1-2
CORRESPONDANCE COULEURS-INDIVIDUS
Bleu : Popul. de reference
Rouge : Pilotes MIRAGE 2000
Marron : Pilotes MIRAGE port.
Fichier : MIRAS.DAT
LISTE DES CARACTERES ETUDIES
Oreillette gauche
Ventricule droit
V.G. diastolique
V.G. systolique
V.G. % raccourciss.
Septum epais. Diast.
Septum epais. Syst.
Septum % epais.
P.Post. epais. Dias
P.Post. epais. Syst.
P.Post. % epais.
Graphe n° 7

ENREGISTREMENT CONTINU DE L'E.C.G. CHEZ LES PILOTES DE MIRAGE 2000*
(Comparaison avec les pilotes de Mirage III et F1)

par

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RESUME.

Un enregistrement E.C.G. continu durant 24 heures a permis de comparer un échantillon de 24 pilotes d'avion de chasse conventionnel (Mirage III et F1) avec 7 pilotes de Mirage 2 000. La comparaison des troubles de l'excitabilité et de la conduction au sol et en vol ne montre pas de différence notable entre les 2 groupes. Un trouble de repolarisation en vol n'a été enregistré que chez un pilote d'avion haute performance. Les différences portent principalement sur les fréquences cardiaques observées en vol. Elles sont nettement inférieures sur Mirage 2 000 alors que les accélérations observées ont été supérieures. Ceci peut correspondre aux caractéristiques différentes des 2 populations, aux types de missions effectuées. On peut également incriminer les problèmes d'adaptation cardio-vasculaire à ce nouveau type d'appareil.

Les avions de chasse modernes, caractérisés par les accélérations intenses et prolongées qu'ils sont capables d'engendrer, constituent certainement un facteur d'agression important pour les pilotes. Il importe de déterminer, en particulier, l'influence de telles accélérations sur le système cardio-vasculaire.

Une étude a été effectuée dans ce sens, en comparant les résultats obtenus avec ceux qui proviennent d'une étude analogue que nous avons effectuée sur des avions de chasse de type plus ancien.

Population étudiée.

2 échantillons ont été étudiés :

- 24 pilotes de Mirage III et Mirage F1, dont l'âge moyen est de 27 ans et ayant une activité aéronautique moyenne de 1 340 heures de vol.
- 7 pilotes de Mirage 2 000, d'âge moyen 30 ans et ayant une moyenne de 2 300 heures de vol. Il s'agit donc, à l'évidence de pilotes beaucoup plus confirmés que les précédents.

Matériel et méthode.

Pour l'ensemble des 31 pilotes, un enregistrement E.C.G. continu ambulatoire de 24 heures (E.C.G.C.) selon la méthode de Holter a été réalisé. De façon obligatoire cet enregistrement devait comporter 1 ou plusieurs missions au cours desquelles une estimation de l'accélération maxima enregistrée était obtenue.

L'étude a porté sur l'évolution de la fréquence cardiaque, les dysrythmies et les anomalies de la repolarisation en distinguant les périodes de vol, l'activité diurne normale et la période nocturne.

Les appareils d'enregistrement utilisés, appareils classiques habituellement utilisés en cardiologie, ont été préalablement testés en centrifugeuse jusqu'à 10 G pour s'assurer de l'absence de fluctuations significatives de la courbe de réponse au cours des accélérations soutenues et de haute intensité. Les résultats ont été tout à fait satisfaisants.

La lecture s'est effectuée à 100 fois la vitesse d'enregistrement avec analyse très précise des anomalies rencontrées grâce à un système de validation soumis à la critique permanente d'un médecin cardiologue.

Résultats.

Missions enregistrées.

Sur Mirage III et F1, au total 39 heures de vol ont pu être analysées de façon tout à fait précise.

Le pic maxima d'accélération obtenu pour l'ensemble des 24 pilotes a été de 6,5 G. La moyenne effectuée sur l'ensemble des accélérations maxima rapportées est de 4,7 G.

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Sur Mirage 2 000, 10 heures de vol ont pu être analysées correspondant à 14 missions dont 9 avec un pic d'accélération supérieur à 6 G. Le pic maximum d'accélération a été de 8,5 G alors que la moyenne des maxima réalisée s'établit à 6,6 G.

Chez 3 pilotes, le facteur de charge maxima s'est accompagné de la survenue d'un voile gris.

Anomalies E.C.G. sur les 24 heures.

Elles sont précisées sur le tableau suivant.

DYSRYTHMIES AU COURS DES 24 HEURES

Tableau I

	Mirage F1 et III	Mirage 2 000
ESA > 10/24 h.	29,2 %	0/7
ESV > 10/24 h.	4,2 %	0/7
BAV I	8,3 %	1/7
BAV II	0 %	0/7

Les extrasystoles auriculaires (ESA) n'ont été prises en compte que lorsque leur nombre était supérieur à 10/24 heures. La même règle a été appliquée pour les extrasystoles ventriculaires (ESV). Il s'agissait toujours d'extrasystoles isolées sans doublets ni salves.

Les anomalies de conduction A-V sont restées toujours mineures (simple allongement nocturne de P-R) et peu fréquentes.

Anomalies E.C.G. enregistrées en vol.

Elles sont précisées sur le tableau suivant.

ANOMALIES E.C.G. AU COURS DES VOLS
(chiffre total obtenu)

Tableau II

	Mirage F1 et III (39 h)	Mirage 2 000 (10 h)
ESA totales	12	0
ES totales	2	1
BAV	0	0
Sous décalage ST	0	1

Les totaux obtenus sont très faibles en particulier pour ce qui concerne les ESV dans les 2 échantillons.

Il n'y a pas eu de troubles de conduction A-V.

Un pilote de Mirage 2 000 a présenté, à l'occasion d'une accélération avec fréquence cardiaque à 140 par minute, un sous décalage franc du segment ST.

L'étude des fréquences cardiaques en vol a permis la comparaison des moyennes des fréquences maxima enregistrées ainsi que la moyenne générale sur l'ensemble de cette période.

Elle est précisée sur le tableau suivant.

FREQUENCE CARDIAQUE EN VOL

Tableau III

	Mirage F1 et III	Mirage 2 000
Fréquence maxima (moyenne)	130,0	116,0
Fréquence moyenne (globale)	93,2	86,4

Il est également intéressant, pour les pilotes de Mirage 2 000 qui seuls ont été victimes de phénomènes de voile gris, de préciser les conditions de ces états critiques.

Elles sont précisées sur le tableau suivant.

PHASES CRITIQUES

Tableau IV

Nombre de GZ Max.	Voile gris	Fréquence cardiaque maxima
8	+	150
8	+	120
6	+	85
8,5	-	105

L'un des pilotes, en particulier, a présenté un phénomène de voile gris pour 6 G seulement avec une fréquence de 85/mn.

Discussion.

Il apparaît nettement qu'il n'y a pas d'augmentation, sur le Mirage 2 000, des anomalies rencontrées en période de vol par rapport aux avions de chasse conventionnels tant en ce qui concerne les troubles de l'excitabilité que de la conduction. Néanmoins, il pourrait exister une sensibilité plus grande de la repolarisation chez ces pilotes. La comparaison ne peut bénéficier, cependant, d'une approche statistique en raison des effectifs modestes actuellement recueillis. Cette étude n'est qu'un préliminaire.

Il nous paraît particulièrement intéressant de la poursuivre en raison du caractère inattendu des fréquences cardiaques obtenues.

On observe en effet des chiffres bien inférieurs chez les pilotes de Mirage 2 000 alors qu'ils ont subi des accélérations nettement plus intenses. On doit faire intervenir à ce niveau les différences d'âge et de compétence aéronautique concernant les 2 populations de pilotes : ceux du Mirage 2 000 étant plus âgés et ayant davantage d'heures de vol à leur actif.

Il faut également faire intervenir la durée des accélérations, qui n'a pas pu être appréciée, et qui a été vraisemblablement plus faible chez les pilotes de Mirage 2 000.

On remarquera enfin que des signes de mauvaise tolérance ont été notés pour des fréquences cardiaques assez faibles, témoignant peut-être de la rapidité de mise en oeuvre d'un tel appareil, dépassant parfois le temps d'adaptation de l'organisme.

Toutes ces hypothèses mériteront d'être vérifiées en multipliant les enregistrements et en précisant au mieux les conditions exactes des missions.

Conclusion.

Les accélérations de forte intensité obtenues sur le Mirage 2 000 ne semblent pas modifier la fréquence de survenue des troubles de l'excitabilité et de la conduction des pilotes lorsqu'on les compare à ceux que présentent les pilotes d'avion de chasse conventionnels.

L'évolution de la fréquence cardiaque est, par contre, différente et pourrait traduire une certaine difficulté d'adaptation du système cardio-vasculaire à ce type de facteur de charge.

LES MODIFICATIONS ELECTROCARDIOGRAPHIQUES INDUITES PAR LES ACCELERATIONS, FACTEUR PREDICTIF DE LA TOLERANCE ?

par

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RESUME

Les accélérations + Gz que subissent les pilotes des avions de combat sont arythmogènes. Sur 328 tracés d'électrocardiographie recueillis chez 146 sujets subissant des accélérations de + 4 à + 11 Gz et d'une durée variant de 20 à 60 sec. nous avons relevé 215 anomalies supraventriculaires sur 181 tracés et 37 anomalies ventriculaires sur 31 tracés.

La fréquence de ces manifestations est fonction de l'intensité de l'accélération. Par contre, il ne semble pas exister de corrélation entre les anomalies électrocardiographiques et les manifestations hémodynamiques responsables des troubles fonctionnels visuels et psychomoteurs. Ce fait enlève à la surveillance électrocardiographique tout intérêt prédictif sur la tolérance fonctionnelle aux accélérations. L'origine de ces troubles du rythme est vraisemblablement liée aux réflexes vagaux provoqués par les manoeuvres de protection au cours de l'accélération et par le brusque retour veineux à l'arrêt de la centrifugeuse.

1. INTRODUCTION

Les premiers troubles du rythme sous accélération ont été décrits avant la deuxième guerre mondiale. VON DIRINGS[illegible], GAUER, avaient déjà démontré le caractère arythmogène des accélérations.

La plupart des études ont montré des troubles du rythme concomitant de la phase d'accélération, peu se sont attachées à observer la phase post-accélération ou phase de récupération. En fait, comme dans l'exercice musculaire, cette phase est riche en anomalies électrocardiographiques. Il existe une certaine similitude dans la sémiologie électrocardiographique entre ces deux situations.

La gravité de certaines manifestations et l'arrivée de nouveaux avions de combat permettant des accélérations élevées et soutenues nous ont amené à rechercher un critère objectif et facile à recueillir de la tolérance physiologique au facteur de charge.

Cette étude a pour but de chercher à établir si les troubles du rythme étaient en relation avec les manifestations hémodynamiques d'une part et la tolérance d'autre part.

2. METHODOLOGIE

Cette étude a été réalisée à partir de 328 tracés d'électrocardiographie enregistrés chez 146 sujets au cours de lancements en centrifugeuse. Le sujet, équipé d'électrodes est assis sur un siège Martin Baker MK IV. Les accélérations sont dirigées dans le sens pied-tête créant une force d'inertie inverse qui s'exerce selon les axes des gros vaisseaux perturbant de façon majeure l'hémodynamique. Les enregistrements ont été effectués avant, pendant et après un plateau d'accélération qui va de 20 secondes à une minute. Les niveaux atteints variaient de 4 à 11 Gz.

3. RESULTATS

Une majorité d'électrocardiogrammes (tableau 1) comporte des modifications puisque sur un total de 328 électrocardiogrammes, 193 présentent des anomalies. Les troubles supraventriculaires sont prédominants avec 182 tracés tandis que les troubles ventriculaires ne sont observés que sur 31 tracés. Un certain nombre de tracés présentent à la fois des troubles du rythme des deux étages du coeur.

Les manifestations supraventriculaires se présentent pour le même tracé, soit sous la forme d'un seul type d'anomalie, et ceci est le fait de 151 tracés, soit sous la forme d'une association d'anomalies, c'est ce que l'on voit sur 31 tracés. On comptabilise ainsi 215 anomalies supraventriculaires.

De la même façon, les manifestations ventriculaires se présentent sur 25 tracés sous la forme d'un seul type d'anomalies et sur 6 tracés par une association de différentes anomalies, ce qui explique qu'on a comptabilisé 37 anomalies ventriculaires.

3.1. - Dysrythmies supraventriculaires (Figure 1)

Les atteintes de la commande sinusale sont très fréquentes puisque l'on observe des arythmies sinusales sur 35 pour cent des tracés et des épisodes de bradycardies relatives sur 11 pour cent des tracés. Plus rarement on observe des échappements nodaux (3,6 pour cent des tracés) et des échappements auriculaires (1 pour cent). Les extrasystoles supraventriculaires sont présentes sur 4 pour cent des tracés.

3.1.1. - Arythmies sinusales

Le plus souvent, il s'agit d'une arythmie respiratoire avec des espaces RR variant de 240 à 440 msec entre les deux phases du cycle respiratoire. Considérées comme physiologiques, elles ont la particularité d'être induites par les accélérations chez des sujets qui n'ont pas d'arythmie respiratoire au repos. En fait, le plus souvent, il s'agit d'une majoration d'une arythmie respiratoire préexistante.

3.1.2. - Bradycardies relatives

Ces manifestations sont relevées à 43 reprises. Il s'agit soit de bradycardies modérées à 60, 55 cycles par minute, soit de ralentissements francs de la fréquence cardiaque par rapport à la fréquence habituelle de repos. Cette diminution brutale est alors de 10 à 32 cycles par minute.

A 10 reprises, nous avons observé des diminutions du rythme cardiaque sur un fond de tachycardie. Il s'agit alors dans ce cas de bradycardies relatives, l'ampleur de cette diminution étant d'une quarantaine de cycles par minute. Ces bradycardies ont été déclenchées dans trois cas par une extrasystole supra-ventriculaire.

L'importance de cette dépression de l'activité sinusale favorise parfois l'émergence de complexes d'échappements jonctionnels voir de lambeaux de rythme jonctionnel ou de rythmes auriculaires ectopiques.

3.1.3. - Les complexes d'échappement

Deux origines différentes ont été attribuées à ces complexes d'échappement.

- Dans 16 cas, ces complexes semblent provenir du noeud d'ASCHOFF-TAWARA et nous les qualifierons d'échappements jonctionnels ou nodaux. Ils sont soit uniques, ou se présentent sous la forme d'association de 3 à 20 complexes consécutifs.

- Sur 5 tracés, ces complexes semblent avoir pour origine un foyer ectopique au niveau de l'auricule. Sur certains tracés, ce foyer est unique : ce sont des échappements auriculaires classiques. Sur d'autres, il est erratique, l'onde P' étant alors de morphologie variable.

Ainsi, dans deux cas on a pu discuter l'existence d'un Wandering Pace Maker. En effet, chez un même sujet nous avons observé au cours de quatre lancements différents la répétition du même phénomène : à savoir un rythme auriculaire ectopique de 82 c/mn sur 3 à 15 complexes. Les complexes QRS sont précédés par une onde P' variable qui indique un axe variable, donc une stimulation d'origine variable.

Comme nous l'avons observé dans ce chapitre, ces échappements et bradycardies sont parfois déclenchés par des extrasystoles auriculaires. Ces extrasystoles peuvent aussi être isolées et dissociées des bradyarythmies.

3.1.4. - Extrasystoles supraventriculaires

Elles sont toujours peu nombreuses et le plus souven observées sous accélération. En effet, dans 10 cas il s'agit d'extrasystoles isolées et dans 7 cas d'une suite de 2 à 4 extrasystoles. Ces prématurités n'affectent pas la morphologie du complexe QRS sauf dans 4 cas où l'on peut envisager la possibilité d'une aberration ventriculaire, étant donné l'élargissement de QRS. Ces extrasystoles sont toujours accompagnées d'un repos compensateur et il n'y a jamais de passage en arythmie complète par fibrillation auriculaire. Mais l'oreillette n'a pas le privilège des extrasystoles et nous en avons aussi observé au niveau du ventricule.

3.2. - Troubles du rythme ventriculaire (Tableau 2, Figure 2).

Les extrasystoles représentent les seules anomalies ventriculaires observées. Elles sont le plus souvent présentes lors de la phase d'accélération. Ces extrasystoles sont uniques sur 14 tracés ou multiples sur 17 tracés.

Dans deux cas il y a des épisodes de trigéminisme et dans 3 autres cas, des épisodes de bigéminisme. Enfin dans 2 cas les extrasystoles ventriculaires sont en salve : dans l'un, c'est une salve de 3 extrasystoles ventriculaires polymorphes, dans l'autre, une salve de 5 extrasystoles ventriculaires. Dans ce cas aussi cette tachycardie ventriculaire est composée d'extrasystoles polymorphes. Toutes les autres manifestations ventriculaires sont monomorphes.

3.3. - Effets des accélérations sur la fréquence d'apparition des dysrythmies (Tableau 3 , Figure 3)

L'apparition de ces manifestations paraît liée aussi au niveau d'accélération puisque si on porte nos résultats sur un diagramme, dont l'abscisse représente l'accélération exprimée en G et l'ordonnée, la fréquence d'apparition exprimée en pourcentage des manifestations supraventriculaires observées

pour une accélération déterminée, on observe qu'à partir de 7 Gz chaque lancement déclenche des manifestations dans près des deux tiers des cas, mais seulement dans moins de la moitié des cas au-dessous de 6 Gz. A 10 et 11 Gz le fait que tous les électrocardiogrammes présentent des modifications n'a pas valeur statistique du fait du nombre restreint d'observations. Mais aucun des sujets ayant toléré de tels facteurs de charge n'a présenté de trouble de l'électrocardiogramme à 5 ou à 7 Gz.

Etant donné le nombre restreint d'extrasystoles ventriculaires observées sur nos 328 enregistrements, il n'apparait pas de relation entre la fréquence d'apparition de ces manifestations et le niveau d'accélération.

3.4. - Relation entre troubles du rythme et tolérance clinique

Sur le plan clinique, aucune diminution du champ visuel, témoignage de la qualité de la perfusion de l'ensemble céphalique et a fortiori aucune perte de connaissance n'est apparue pendant ces dysrythmies. En particulier, il n'a pas été observé d'altération du champ visuel lors des phases d'extrasystolies. Les manifestations cliniques traduisant une intolérance aux accélérations que nous avons observées ont toujours été dissociées des troubles du rythme.

4. DISCUSSION

Notre étude met en relief deux types de modifications majeures du rythme cardiaque chez l'homme soumis aux accélérations intenses et prolongées.

Les troubles de la commande sinusale qui sont évoqués dans notre étude surviennent essentiellement à la phase de récupération. Seules, les extrasystoles auriculaires sont observées le plus souvent pendant la phase d'accélération. Ce type de ralentissement sinusal a été rapporté par SCHUBROOKS (1972). Dans la publication de cet auteur on note, chez deux sujets, l'installation d'un rythme jonctionnel. Dans le premier cas, il s'agit d'un rythme auriculo-ventriculaire à 80 c/mn qui survient après une pause sinusale de plus de 700 ms. La pause apparaît à la 24e seconde d'un test sous fort facteur de charge (+ 8 Gz) et s'évanouit à l'arrêt de la centrifugeuse. Il faut noter que, lors d'un second lancement, le même sujet présentera une nouvelle fois un rythme ectopique identique, à ceci près qu'il se poursuivra après l'arrêt du test, étant alors responsable d'une bradycardie franche à 50 c/mn.

Depuis quelques années, on accorde une plus grande importance aux dysrythmies qui apparaissent non plus au cours de l'accélération elle-même, mais à son décours, voire même lors de la phase de récupération qui suit l'agression. C'est le cas de WHINNERY (1966) qui insiste sur la fréquence des arythmies sinusales après des tests en centrifugeuse chez 22 sujets venant de subir des tests à 4,5 et 7 Gz pendant 15 secondes.

Enfin, se pose le problème des relations entre les manifestations cliniques des effets physiopathologiques des accélérations et en particulier des effets hémodynamiques cérébraux d'une part, et les manifestations électrocardiographiques d'autre part. En d'autres termes, il s'agit de savoir s'il existe une relation entre la tolérance aux facteurs de charge et les dysrythmies telles que nous les avons décrites. Il est en effet possible que les bradycardies limitent l'efficacité des réflexes correcteurs d'origine sino-carotidienne ou aggravent la chute du débit cérébral et participent à l'étiopathogénie des troubles visuels ou des pertes de connaissance. KIRKLAND et coll. en 1976 et WHINNERY et coll. en 1979 ont publié l'observation d'une perte de vision ou de connaissance contemporaine d'un trouble du rythme.

En ce qui nous concerne, nous n'avons jamais observé de trouble du rythme associé à une manifestation clinique. Nous n'avons jamais observé de bradycardie pendant la phase d'accélération et toutes les modifications du tracé électrique, même majeures, n'ont jamais eu de traduction clinique d'autant plus que ces phénomènes survenaient pendant la phase d'accélération. Dans tous les cas où déficits visuels ou troubles de conscience ont amené à interrompre le lancement, le tracé électrocardiographique s'est révélé absolument normal. Sans pouvoir répondre définitivement à la question, le fait que les dysrythmies que nous avons rapportées, aussi bien que celles qu'ont décrites les auteurs américains, soient d'autant plus importantes que l'accélération est intense nous paraît être un solide argument de présomption en faveur de l'action directe du facteur de charge sur le rythme cardiaque, même si le trouble du rythme n'apparait qu'à la cessation de la contrainte et même si des mécanismes physiopathologiques neuro-hormonaux ou métaboliques intermédiaires sont impliqués.

En ce qui concerne les troubles de l'excitabilité on distinguera ceux de l'étage supraventriculaire et ceux du ventricule. Les troubles de l'excitabilité auriculaire sont peu fréquemment rencontrés lors d'accélération + Gz. Ni TORPHY et coll. (1966), ni SHUBROOKS (1972) n'observent d'augmentation significative du nombre d'extrasystoles avec cet axe d'accélération. Ce fait est en parfait accord avec nos résultats à l'opposé de ceux de ZUIDEMA Coll.(1956) et WHINNERY (1966) qui les observent à la phase de récupération.

Les troubles de l'excitabilité ventriculaire sous accélération sont très fréquemment rapportés bien que leur fréquence et leur gravité soient très variables d'une observation à l'autre. TORPHY et coll. (1966) n'observent pas d'extrasystoles ventriculaires pour des accélérations de haut niveau qui sont à l'origine de pertes totales de la vision. SHUBROOKS (1972) constate que 93 pour cent des sujets qu'il soumet 45 secondes à des accélérations de 6,5 à 9 Gz en présentent. Le nombre de ces extrasystoles est plus important à 9 Gz qu'à 6 Gz. Dans notre étude, l'incidence des accélérations sur l'apparition des extrasystoles ventriculaires est faible puisqu'elle n'atteint pas 10 pour cent. Par contre, comme nous, WHINNERY et coll. (1980) décrivent un lambeau de tachycardie ventriculaire à l'arrêt de la centrifugeuse. Les différences notables de fréquence d'apparition de ces troubles du rythme d'une étude à l'autre tiennent

vraisemblablement à la multiplicité des protocoles utilisés et très probablement aussi au recrutement des sujets étudiés.

L'origine de ces anomalies électrocardiographiques n'est pas encore clairement établie. Certains auteurs allèguent des troubles de la commande extrinsèque du coeur et voient dans les troubles de l'excitabilité une dystonie neuro-végétative. D'autres font appel à des modifications de remplissage des cavités cardiaques sous facteur de charge alors que d'autres encore pensent à des troubles ischémiques myocardiques. Enfin, les changements de position du coeur dans le médiastin provoqués par les forces d'inertie seraient impliqués dans le processus. Les très nombreuses mesures de flux ou du débit coronaire effectuées chez l'animal ne permettent pas de démontrer la nature ischémique de ces manifestations. De la même façon, les dosages sériques des enzymes témoins de la contraction myocardique (SELLERS et coll. 1977) n'ont jamais permis de mettre en évidence une souffrance myocardique de type hypoxique.

Ces troubles du rythme pourraient être liés à des facteurs hémodynamiques (LEGUAY, 1983) et aux réponses excessives de régulation (WICHITZ 1975). En effet, lors des accélérations + Gz, les modifications hémodynamiques entraînent une hyperactivité orthosympathique avec levée du tonus vagal s'expliquant par une mise en jeu des barorécepteurs sino-carotidiens et aortiques. L'ensemble des effets de cette régulation, associés aux réactions de stress augmentant le taux de catécholamines circulantes seraient à l'origine des troubles de l'excitabilité myocardique (SHUBROOKS 1972, WICHITZ 1975).

Les troubles du rythme qui apparaissent à l'arrêt de la centrifugeuse ou dans les premières secondes qui suivent peuvent s'expliquer par les réflexes mis en jeu lors du retour brutal du sang veineux aux cavités droites, mais aussi par l'importance du tonus parasympathique. Ce tonus serait alors à l'origine des bradycardies, des blocs sino-auriculaires, des échappements. Les sportifs, les longilignes, seraient plus sujets aux troubles du rythme que le reste de la population. Il ne s'agit pas pour autant de manifestations d'intolérance, mais le témoignage de la prépondérance du nerf vague dont l'importance serait liée au niveau d'accélération (CLERE et coll. 1984).

5. CONCLUSION

Les dysrythmies observées lors des lancements en centrifugeuse sont pour l'essentiel des troubles bénins de la commande sinusale, identiques à celles que l'on observe dans d'autres circonstances chez le sujet sain lors de la pratique sportive notamment. Plusieurs observations viennent toutefois renforcer la notion de l'existence de dysrythmies plus graves et notamment ventriculaires. Malheureusement, ni la signification physiopathologique, ni même le pronostic de ces troubles du rythme ne sont parfaitement établis.

Ces dysrythmies posent le problème de la sélection et du suivi médical des pilotes de combat. Des tests électrocardiographiques en centrifugeuse doivent-ils être utilisés pour sélectionner et suivre l'entraînement des pilotes aux accélérations ? En fait, en l'état actuel de nos connaissances, les anomalies électrocardiographiques ne semblent pas présenter un facteur limitant aux accélérations et ne jouent à cet égard qu'un rôle de second plan devant les troubles de l'hémodynamique cérébrale.

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TABLEAU 1

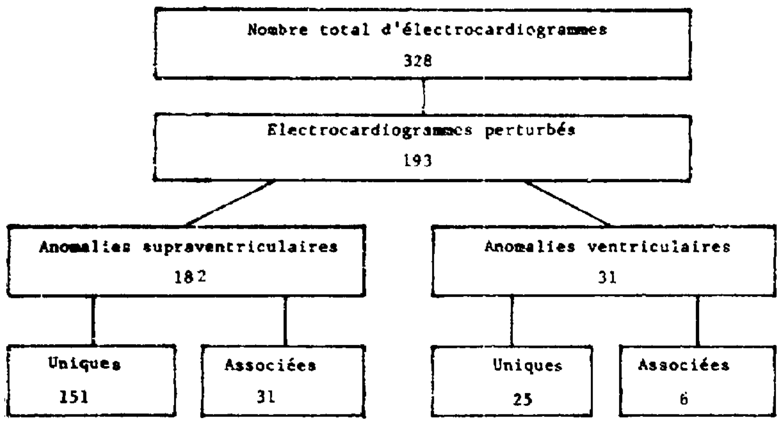

FIGURE 1

REPARTITION DES ANOMALIES SUPRA VENTRICULAIRES

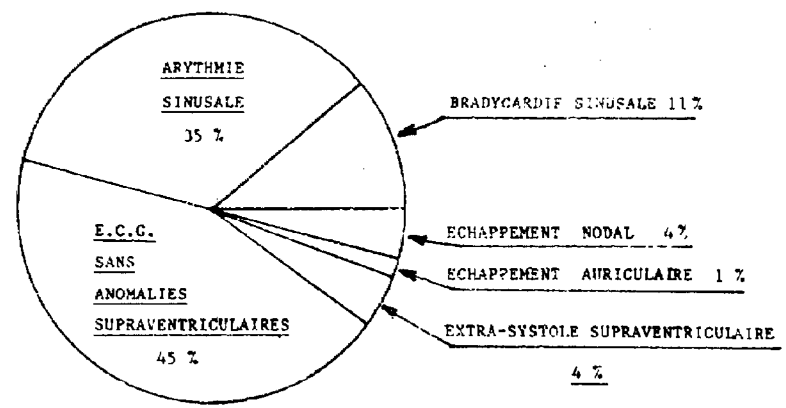

TABLEAU 2

DIFFERENTES EXTRA-SYSTOLES VENTRICULAIRES

EXTRASYSTOLES				NOMBRE d'ECG
. Isolées	.	.	:	14
. Multiples	.	.	:	10
. Trigéminées	.	.	:	2
. Bigéminées	.	.	:	3
. En salve	.	.	:	2
TOTAL	.	.	:	31

FIGURE 2

REPARTITION DES EXTRA-SYSTOLES VENTRICULAIRES

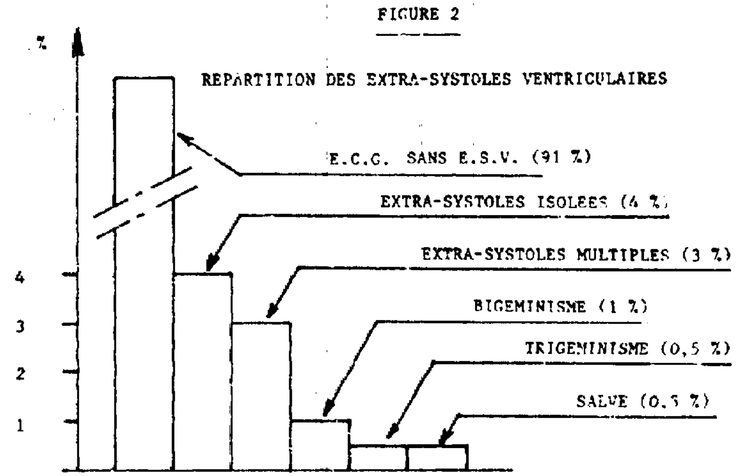

TABLEAU 3

DIFFERENTS TROUBLES DU RYTHME SUPRAVENTRICULAIRE.

Accélération (Gz)	4	5	6	7	8	9	10	11	TOTAL
Arythmies sinusales	4	31	26	33	28	11	1	0	134
Bradycardies	2	7	5	17	4	4	3	1	43
Echappements nodaux	0	3	1	9	1	2	0	0	16
Echappements auriculaires	0	0	0	3	2	0	0	0	5
Extra-systoles auriculaires	0	5	5	4	2	0	1	0	17
TOTAL	6	46	37	66	37	17	5	1	215

FIGURE 3

REPARTITION DES ANOMALIES SUPRA-VENTRICULAIRES EN FONCTION DU FACTEUR DE CHARGE.

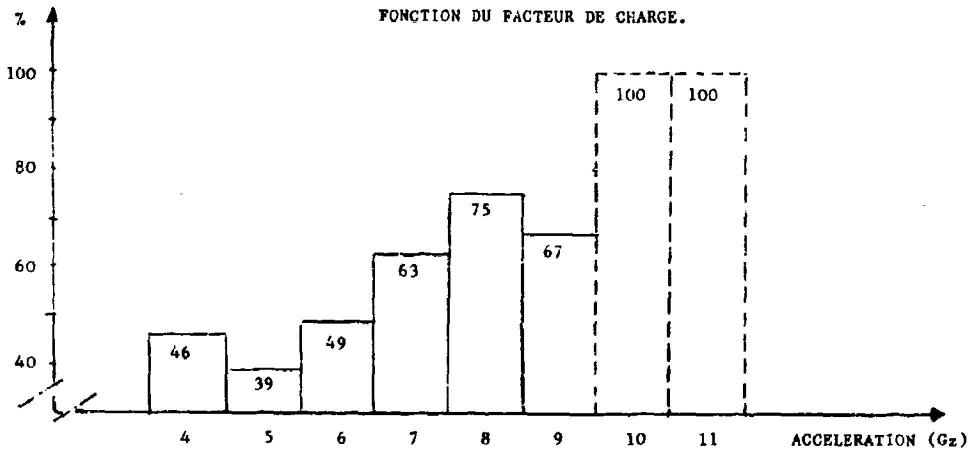

TABLEAU 4

EFFET DE L'ACCELERATION SUR LES ELECTROCARDIOGRAMMES.

Accélération (Gz)	4	5	6	7	8	9	10	11	TOTAL
Nombre d'enregistrements	13	92	67	87	44	21	3	1	328
Nombre d'électrocardiogrammes présentant des anomalies supra-ventriculaires	6	36	33	55	33	14	4	1	182
Nombre d'électrocardiogrammes présentant des anomalies ventriculaires	1	4	3	19	3	0	1	0	31

DISCUSSION OF SESSION III - MEDICAL SELECTION: CARDIOVASCULAR ASPECTS

(Papers 31, 32, 33 and 34)

COL PSIMENOS (GR)

I would like to ask Dr Hickman if you have a standard scheme for high G resistance physical fitness programme? Not high G training but a physical fitness programme for the pilots of high performance aircraft?

AUTHOR'S REPLY (COL HICKMAN (US))

Gen DeHart actually had a back up slide to show the USAF pilot physical fitness programme which is well defined. It comprises a rather low level of aerobic exercise and consists in greater part of weight lifting and resistive exercises. The programme has until now been voluntary and because of the heavy schedule of other activities it has not been followed by all pilots. However, the programme is now standardised and Gen DeHart is recommending that it should be made mandatory.

COL PSIMENOS (GR)

I would like to ask one more question about selection. Of course we have been discussing medical selection and I am sure that there is another selection before or after - psychotechnic selection/psychological selection?

AUTHOR'S REPLY (COL HICKMAN (US))

Yes, there are multiple selections but the driving force at the branching point in a dual track system is not medical. If the system evolves as we hope it will, the choices will be made administratively. The best candidates to become tanker, bomber and transport pilots (for whatever composite skills makes the best tanker, bomber or transport pilot) will be identified before the fighter attack reconnaissance medical screening is done. Thus the screening will not dictate who becomes a fighter pilot but the choice of fighter pilots will be based upon attributes of training and performance. However, a small number of those selected will not be able to become fighter pilots because of physical defects. But the equation is not driven by the advanced medical screen, administrative selection comes first. Actually, if the programme evolves as Gen DeHart has set it up, these aircrew will actually go to specific fighter attack and reconnaissance bases before the advanced medical screening is carried out. This would allow us to perform the advanced medical screening at three bases rather than seven. Thus the selection will be made and the aircrew member will go to another location before the advanced medical screening is done.

LT COL GRAY (CA)

I have a question for Dr Hickman. The cardiovascular screening that you recommend is, as it should be, non-invasive in nature but I wonder what you do with the candidate in whom you identify an abnormality. I'm thinking for instance of somebody with a WPW pattern, whom you reject and who decides on his own to go outside and have further invasive testing and electro-physiologic studies. If a candidate does that on his own would you then be willing to look at him again?

AUTHOR'S REPLY (COL HICKMAN (US))

Yes, this is an area in which we have had to set policies. We believe that invasive procedures should be restricted to those who are already engaged in a dangerous occupation. We do not believe that procedures with risk ought to be applied to those who only want the opportunity to learn a dangerous occupation. Since at least 25% to 30% of aircrew candidates will not make it for other reasons, there is no guarantee that the individual on whom you perform a cardiac catheterisation in order to determine that he is fit to enter flying training has the right compositive psychomotor skills to become a pilot. The overwhelming majority of aircrew leave the Air Force after only 5 years. Thus only a very small number of those requiring investigation would remain in the Air Force for a full career, and thus we believe that the risk associated with invasive investigations in untrained aircrew is unacceptable. Now I had a list of conditions such as Wolff-Parkinson-White ECG finding, left bundle branch block, exercise induced ventricular tachycardia and a whole host of abnormalities in which we could, using invasive electro-physiologic studies, clear individuals for flying training. We recently had a case of an Air Force Academy graduate with Wolff-Parkinson-White who wanted to go to flying training. We turned him down. He finally found a university professor who was willing to perform a 3 day electro-physiologic study. The study proved conclusively that the officer's by-pass tract would not conduct anti grade faster than 120 beats per minute and that it would not conduct retrograde at all. This meant that he did not have true ventricular pre excitation but only had a vestigial by-pass tract. For the university professor this represents one interesting case. For us, whether one person or 49 persons out of 50 has it, we would still have to carry out the full investigation. I think the university professors would grow very weary if they became a centre for invasive studies in those who had not yet even learnt to fly. We entered this Air Force Academy graduate into flying training. It would have been unreasonable not to do so. This case has, however, not changed our feeling about the reservation of dangerous procedures only for those who are in dangerous occupations. We realise, however, that if we were prepared to carry out invasive procedures we would clear many more people for pilot training.

MÉD GÉN INSP COLIN (FR)

Dr Dider, you were kind enough to present the paper (No 33) by Drs Seigneuric and Leguay reporting 24 hour ECG recordings in pilots in flight and on the centrifuge. I would like to put a short question in connection with the differences between the results obtained on the centrifuge and those which occurred in flight. May they not have been due to the sensory illusions which accompany the deceleration of the centrifuge?

AUTHOR'S REPLY (MED CLERE (FR))

Yes, this is one of the main problems that arose when we analysed our results. To my mind, very often we tend to think that all these arrhythmias are linked to the conditions of the trial (acceleration stress). In

particular, there is the problem of sensory stimulation. What I would like to do is to try to simulate the sensory stimulus. I would choose subjects with marked arrhythmias, put them in a centrifuge with a gondola which is tilted gradually as the G increases. Then, a few days later, I would test them again with pre-tilting of the gondola in advance so that there is no sensory stimulation. Such a study should show the effect of the senory stimulation. Another possible cause of the difference that occurs between a fighter aircraft and the situation prevailing in a centrifuge is that as the centrifuge slows down the subject is in a passive recovery phase, he does not speak or move and so there is a sudden return of the blood to the atrium. Whilst in the situation of the fighter pilot in the aircraft even when the G ceases the pilot is still exposed to flight stress, and consequently the phenomenon will be less important in this situation. There may be other combined reasons, may be some members of the meeting here could help me find another explanation?

COL VAN DEN BIGGELAAR (NL)

Our experience with centrifuge training is that the stress is very large so that you could postulate that the high heart rates which occur under G on the centrifuge are due to the effect of adrenalin, and that this effect is less in the aircraft. We have not, however, recorded the ECG in flight. Of course, as you stated, another factor which is introduced by the centrifuge itself, is the high stimulation of the semicircular canals. Even if the gondola is pre positioned at a certain bank angle before the centrifuge starts rotating, there is stimulation of the vertical canals whenever the G changes. This appears to the subject as a tilting of the whole cabin. It is quite a stress factor which has to be taken into consideration. I am very surprised at the low heart rates which you found under G in actual flight. They are much lower than those which we found in the centrifuge.

AUTHOR'S REPLY (MÉD CLERE (FR))

I agree with you that semicircular canal stimulation can occur even with a pre positioned tilt. May be, however, I did not explain adequately that we recorded heart rates during the onset and during the plateau acceleration phases which are quite similar to the results found in other centrifuge studies but that most of the arrhythmias occurred during the recovery phase. Thus during the 15 seconds after the cessation of G some subjects show a sudden slowing of the heart rate with the heart rate falling from 140 to 100 or even lower. This is what was quite surprising to us. I would like to explain also the object of our experiments. In our laboratory, for various reasons, we test pilots who have had a problem while flying, such as loss of consciousness or in whom an arrhythmia has been found. We run them on the centrifuge to determine how they behave under well defined conditions. Originally we performed tests at up to 5 G but for the last 2 or 3 years we have conducted the tests in two stages. The first stage comprises a rapid onset rate going to 4, 5, 6, 7 G with 5 sec plateau at each level. Thirty minutes later the subject is exposed to sustained 7 G. We have found that arrhythmias are more frequent in these tests than had occurred in the 5 G test. We ask ourselves the question "What are we going to do with such people?". Are these people to be rejected or is it really a minor sign which should be ignored? This is why we started the study. We concluded from it that not all arrhythmias are necessarily pathological. I remember an experiment conducted 2 years ago with a test pilot who was exposed to four different runs separated by 30 second intervals. Each run lasted 1 minute and the maximum acceleration was 9 G. We observed arrhythmias during this experiment but they were related to the stress and it wasn't a sign of severe pathology.

COL VAN DEN BIGGELAAR (NL)

We have no such elaborate data from our centrifuge training. About 20% of the cases that we evaluated had isolated PVCs. All the PVCs occurred at above 6 G which corresponds with your findings. If the G is increased in steps every so many seconds the procedure is extremely fatiguing for the subject. We use a slightly different G pattern as I'll explain in my paper.

COL HICKMAN (US)

I certainly admire the willingness of your French aviators to wear Holter monitors in flight and to be experimental subjects. Our aviators are very reluctant to be monitored. We cannot grant them a King's pardon if they have a serious arrhythmia even though the exposure has been for experimental purposes. What was your aeromedical disposition of the case with ventricular tachycardia? Was he an aviator? Did you waiver this individual to continue flying as a fighter pilot with ventricular tachycardia?

AUTHOR'S REPLY (MÉD CLERE (FR))

The subject was not a pilot so there was no waiver to be awarded. We are quite cautious and wary.

COL HICKMAN (US)

And if a Mirage pilot has a 4 or 5 beat run of ventricular tachycardia on the Holter monitor during flight what will you do?

AUTHOR'S REPLY (MÉD CLERE (FR))

This really is a problem because the pilots who we use for our experiments know that doctors are testing them so that they are always anxious with respect to their medical fitness to fly. I have to try to place myself in the situation that I have when I am a consultant examining a patient referred by another physician, when I would have to report any abnormality which I found. There is a problem here with respect to the mutual confidence between patient and doctor. It is a rather delicate situation. In this situation I would try to persuade the pilot that it is a significant finding and that he should make the decision to have it investigated further. I am not going to make the decision for him.

MÉD EN CHEF ILLE (FR)

A similar problem did arise in connection with ventricular dilatation and tri cuspid insufficiency which we discovered just by chance. The case was a fully fledged, very able pilot who had started his training on

Mirage 2000. We found the defect when we introduced echocardiography on an experimental basis. The medical decision that he was not fit to fly the Mirage 2000 was not well received either by the pilot or Command. Eventually, the problem was solved as follows: the pilot was interviewed and we explained to him the risks he would be taking in exposing himself to high accelerations with the proven tri cuspid insufficiency; eventually he decided to abandon his training on the Mirage 2000. This was a very specific and special case. It should not conceal trees in the forest. Physicians will have problems of ethics in such circumstances. When pilots act, as experimental subjects for us we must accept that we may have to make a decision as a medical expert.

COL HICKMAN (US)

The reason that I specifically asked about ventricular tachycardia is that, in the US Air Force prior to 1980, if an aviator had technical ventricular tachycardia, which is 3 beats in a row, on any kind of stress test, whether it was treadmill or centrifuge or a bicycle muga, it was permanently disqualifying from flying status. We followed up 45 aviators who had been grounded for 3, 4 or 5 beat runs of ventricular tachycardia at peak exercise for a mean period of 6 years; the mean age was 40, 20% of this group had an acute cardiac event, either angina infraction on sudden death within 6 years. We could not accept an event rate of 10% in 6 years and yet nothing happened to 4 out of every 5 of those aviators with ventricular tachycardia! In order to return an aviator in the US Air Force who has had ventricular tachycardia back to flying status he must undergo a thorough non invasive and invasive evaluation because the major underlying disease is coronary artery disease. Of those who died suddenly the cause was either prolapse or coronary artery disease. In one case it was amyloid. We cannot overlook an episode of ventricular tachycardia although we recognise that most episodes of complex ventricular arrhythmias occur during peak autonomic outflow. Its interesting to note that your incidence of 0.5% of ventricular tachycardia is exactly identical to ours, once in every 200 times.

MED EN CHEF ILLE (FR)

I fully agree with Dr Hickman that ventricular tachycardia must be taken seriously. The action here appears to be quite logical and obvious. It seems to me, however, that a problem does arise in relation to an isolated ventricular systole in a subject of about 35 years of age. For example, a subject who smokes who has a cholesterol level of 2.5 and who is not abiding by the hygiene and dietary instructions which are given to him. Should he be prohibited from flying or should we try to impose upon him further non invasive and invasive examinations. What is the attitude of the US Air Force in this matter?

AUTHOR'S REPLY (COL HICKMAN (US))

This opens up a very important, deeply ethical question. The question, as you pose it, is what would we do with individuals who have high cardiac risks but continue to fly? We do not ground anyone for cardiovascular risk but we have a series of thresholds based upon a regression equation. Based upon these thresholds they may be required to have non invasive studies at their own base or, if they go above a certain level, they automatically have to come to USAF SAM for a cardiac evaluation. We stage our evaluations accordingly to look for asymptomatic disease. Unfortunately about 30% of coronary artery disease cannot be explained on the basis of cardinal risk factors so when we are presented with a case of ventricular tachycardia in someone with no apparent risk factors for aviation medical purposes the problem is still not simple.

I would like to make another comment, if there is time. It relates to an area that Dr Didier has already brought up regarding echocardiographic changes in pilots. We could discuss for a long time the different mechanisms but I just want to add very quickly a couple of things which I think that the AGARD Aeromedical Panel should be attentive to. We have for a long time been returning aviators in the US Air Force with left bundle branch block to flying status if they have a normal angiography and a normal bundle of His. We have seen elevated left ventricular end diastolic pressures, we are seeing abnormal thallium scans in the septum of left bundle branch block cases with no coronary disease. We began to see these patients in 1969 and 15 to 20 years later a certain proportion that is in excess of 5% are starting to show clinically significant cardiomyopathy. Similar findings are occurring at the Mayo Clinic in North West Orient airline pilots with left bundle branch block. In our patients, with abnormal treadmills but who have normal coronary arteriograms, most of the ventricular premature beats during exercise if they have a normal ST segment response come from the left ventricle rather than the right ventricle. Dr Forlin. at USAF SAM a number of years ago, saw persistent T vector changes in the vectorcardiogram after human centrifuge studies. What I am getting to is that we are placing people back on flying status who are perfectly healthy, with what we presume to be minor disorders, but we do not have a clear idea as to whether or not long term, repetitive, after load increases and perhaps even ischaemic changes are occurring in the myocardium. We are now faced with the question of whether this is even occurring in the normal ventricle, even someone who has no sub clinical problem. We have had great difficulty in persuading the operators to accept the fact that repetitive, high sustained G may be a very dangerous long term unquantitated environmental hazard. We are not handling it the way we handled radiation and other similar hazards where we introduced dosimetry and appropriate preventive measures. I really believe that the members of the AGARD AMP need to pool their data, they need to take a long, hard look at a plan to have parallel, age-matched, one for one studies so that this question can be answered. Twenty 20 years from now when the first aviator with a congestive cardiomyopathy that may be totally unrelated to flying turns up and says "Do I have congestive cardiomyopathy because of 20 years in the F16?" What will we say? Given the political climate I think that the military will get the blame whether there is any relationship or not. I believe that ethically we can't go much further without having a firm, strong plan to find the answers to these kinds of problems. This is not a physical standards problem because they pass all of the standards. If we do not come up with a plan and sell it well among ourselves we will not have served the aviators as well as we might.

DR ALNAES (NO)

I had a question for Dr Ille. Of course the two populations that were slightly different in some echocardiographic parameters, ventricular thickness and right ventricle dilatation, were statistically matched in such a way that all mean values were virtually identical. Now I wondered whether they were also matched in other parameters like, for example, physical fitness, aerobic capacity and so on? We all know that fighter pilots and transport pilots also lead very different lives outside the cockpit. Did you investigate these areas to see whether your findings were just a case of athletic heart for example?

AUTHOR'S REPLY (MÉD EN CHEF ILLY (FR))

Both populations were quite similar as regards anthropometric criteria. Unfortunately it was impossible to study family history in depth. More adequate protocols might have done it but we decided that we would launch this exercise when we were requested to decide whether the aptitude or capacity standards should be changed for pilots who are to operate the Mirage 2000 so we tried to have a good basis for comparison. As you saw, the two populations were identical, the same age, the same size, the same weight. But, as you say quite rightly, I have no idea which people smoked or the extent of their physical activities. It is well known that transport aircraft pilots do not practice sport as do fighter pilots or physical exercise as do fighter pilots and also that transport pilots, because of the long hauls they have to fly, will smoke more than fighter pilots. So some elements were not exactly similar. I don't think that these deficiencies were sufficient to explain the echocardiographic differences which we were able to measure. I must say that initially the discrepancies were not striking because the values were just at the upper limits of normality. Thus if we had not been particularly attentive to such data then we might have missed it. It was only on the basis of statistical studies that we were led to think that there was significant differences between the echocardiographic findings of the two groups of aircrew. However in answer to your question, I must say that it was difficult for us to collect information on all the factors which might explain the observed differences.

ENTRY VISUAL STANDARDS AND OCULAR EXAMINATION TECHNIQUES FOR FUTURE FIGHTER AIRCREW

by

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SUMMARY

The visual tasks of future fighter aircrew are likely to increase both in magnitude and complexity. The increasing adoption of devices for visual enhancement and protection, even now, poses problems of the integration with spectacles.

The visual standards required for initial selection for training as a pilot or navigator should, if numbers permit, be such that trained aircrew are unlikely to require a visual aid until presbyopia physiologically demands correction in the latter half of the fourth decade.

This paper will discuss the visual standards considered apposite for future fighter aircrew and the related ocular examination techniques both conventional and those designed to test such specialised ocular functions as stereopsis, glare resistance, dark adaptation, hue discrimination and modulation transfer function.

INTRODUCTION

The visual task of current fighter aircrew is already demanding and it is likely to increase in future generation aircraft fitted with new weapon systems. Although the pilot's role is the most visually demanding, the navigator is also increasingly required to operate complex optical and electro-optical devices. When these are coupled with protective devices, which in turn may cause a reduction in the field of view, diminish the luminous transmittance, introduce optical errors, reflections and haze, the visual load is compounded. Any increase in that load resulting from a decrement in ocular function, reducing the appreciation of one or more of the three visual senses of form, light and colour may well be unacceptable in combat. The other disadvantages associated with spectacles and contact lenses and their integration may also be unacceptable in that context.

DISADVANTAGES OF SPECTACLES AND CONTACT LENSES IN FLIGHT

Entry visual standards for aircrew vary widely between nations. The pragmatic approach of tailoring visual standards to the availability of recruits is often the determining factor. It is sometimes assumed that because spectacles or other visual aids will restore vision to the level demanded by the task, the disadvantages associated with their use are relatively unimportant, but this is not always true.

Veiling glare reduces contrast between target and background and causes considerable problems, particularly, when the cockpit is in sunlight and the aviator is searching an area in shadow. Under these conditions visual search and collision avoidance is more difficult, Clark (Ref 1). Veiling glare is largely produced by haze in transparencies caused by dirt, mist, scratches or inherent material haze and is additive when looking through a variety of transparencies such as windscreen, deicing system, head up display combiner, helmet visors and respirator. The addition of a further transparency either in spectacle or contact lens form only compounds the problem. Reflections from and between transparencies may also prove troublesome, but these can be minimised by anti reflection coatings. These coatings, however, cannot be applied to many transparencies and are both expensive and fragile.

Aircrew using night vision goggles (NVGs), or other optical equipment, may be provided with devices incorporating a dioptre adjustment typically in the range -3.00 to +2.00.D. This will provide a correction for spherical errors but will not correct astigmatism. The optical design of some equipment does not provide the facility of a simple dioptre adjustment or even permit its incorporation. It is also very uncommon to find designs which permit cylindrical lenses to be held at the angles peculiar to an astigmatic aviator. It can, also, be difficult to integrate spectacles with optical equipment by virtue of limited eye relief, incompatability with eye piece shr[illegible] because of oscillation of spectacles on the face during vibration in high speed [illegible]vel flight. Fighter aircrew using NVGs require a protective shield between the eyes and the NVGs. The limited eye relief of some NVGs will not permit both spectacles and protective shields to be worn. This problem also occurs with respirators when the design of the visual area demands a dedicated spectacle design. Lenses may have to be positioned close to the eyes with the attendant problems of contamination by the grease on lashes. Some respirators and protective shields also require lenses to be set at angles to the visual axes in order to fit within the limited spatial envelope. This is undesirable and in higher powers of lenses may require a modification of prescriptions.

Future protective and enhancement devices are increasing in their complexity and their integration with spectacles is likely to be even more difficult and expensive.

Trials have proved the acceptability of contact lenses in the aviation environment, Brennan (Ref 2) and the problems involved with integrating spectacles with optical devices are largely overcome by their use. Contact lenses do, however, present problems of their own. Where aircrew may be compelled to fly intensive operations it would be necessary to use high water content lenses that could be worn constantly, for periods in excess of 48 hours. Such lenses can be difficult to maintain in a military environment and, exceptionally, may result in ocular pathology. Contact lenses are not tolerated by all and some medical conditions may temporarily or permanently preclude their use. The visual acuity achieved can vary and may not match that obtained with spectacles. Foreign bodies behind the lens could be a flight safety hazard. New lens materials may resolve many of these problems peculiar to military aviation and result in contact lenses being the corrective appliance of choice in the future.

VISION STANDARDS FOR PILOTS AND NAVIGATORS ON INITIAL ENTRY AND EXAMINATION TECHNIQUES

Form Vision

The appreciation of shape and detail is largely dependent upon the dioptric mechanism producing a sharply focussed image on the retina, particularly at the fovea, of an object, at any required distance from near to infinity. This ability to project a sharp image is dependent not only on the eye being emmetropic but also on its accommodative ability. Ametropes may either consciously or sub-consciously develop techniques to minimise their disability. Myopes whose far point is nearer than infinity (> 6 metres) may, briefly, improve distance vision by 'screwing' their eyelids or by rapidly blinking, thereby decreasing their effective pupillary aperture and thus increasing their depth of field. These tricks are only partially effective, particularly under low light conditions, and are fatiguing to maintain. Conversely hypermetropes, whose far point is beyond infinity, require to accommodate to see clearly at distances of 6 metres or greater. This reduces the availability of accommodative power to see near objects, particularly under red lighting. Maintaining constant accommodation is also fatiguing especially when stressed and the amplitude available decreases with age. Compensation for astigmatism dependent on type and extent is more difficult.

The Snellen test type is the standard test of vision, in which letters of diminishing size are presented on a chart illuminated by 500-1000 lux. The letters are black on a white background and are thus of high contrast. At the normal test distance of 6 metres the 6/6 (20/20) letter subtends 5 minutes of arc and the detail within the letter, such as the gap in a C, subtends one minute of arc. This visual angle produces an image size on the retina of 2-3μm, which is approximately the diameter of a macular cone.

The testing of distance and visual acuity is important and should not be delegated to untrained personnel. The candidate should be seated 6 metres from the chart in a room, which is also illuminated to similar level as the Snellen chart, with all glare sources shrouded. The eye not being tested should be covered and the tested eye observed to ensure that the candidate does not 'screw' or rapidly blink. Should he do so, it can be prevented by applying upward pressure on the eyebrow, over the supra-orbital ridge, ensuring that pressure is not applied to the globe. The smallest line at which no errors are made is recorded and that eye is then covered by the examiner, before a new chart is presented to the other eye, to preclude learning.

The testing of the amplitude of accommodation or near vision should be carried out in each eye separately, with and without the normal distance correction, if necessary, and then binocularly. Useful instruments are the RAF or equivalent Near-Point Rules; these rest against the patient's face below the infra orbital margins and permit a rotating carrier of reduced Snellen types to be brought towards the eyes. Having determined the nearest distance at which the appropriate type is correctly read it is possible to read the accomodative ability in dioptres and to compare this with the age related mean Duane limits. The visual acuity standards required for initial selection for training as a pilot or navigator should be such that trained aircrew do not require to wear corrective lenses in order to achieve normal vision until the normal reduction of the amplitude of accommodation, which usually becomes evident in the fourth decade, necessitates the use of corrective lenses for reading. This situation can be achieved by raising the visual standards required for entry into pilot/navigator training.

Visual Acuity Standards

The unaided visual acuity at 6 metres should not be less than 6/6 (20/20) in each eye separately.

The accommodation in each eye should be at least the mean for age, as defined by Duane. This, in conjunction with limits on hypermetropia, will ensure that aircrew are unlikely to require a presbyopic correction prior to 45 years of age.

Permissible Refractive Errors

The refractive range for each eye should be within the limits 0 to $+1.75m^{-1}$ in any meridian, the astigmatic element not exceeding $0.5m^{-1}$. A significant family history of myopia warrants special attention. A refraction under cycloplegia is at the discretion of the examiner but if performed should be followed by a post mydriatic test of visual acuity.

Ocular Muscle Balance

The presence of a manifest strabismus or heterotropia normally precludes aircrew training. Orthophoria is, however, rare and minor degrees of latent strabismus or heterophorias are acceptable in flight provided that the fusional ability of the eyes and the primary distance cue of stereopsis are not impaired. Heterophorias of large extent may be well controlled at rest, under stress or fatigue control may be lost resulting in symptoms that may include diplopia.

The presence of heterotropias or heterophorias is best detected by means of the simple cover test. This test should be applied at both 0.6m and infinity by requiring the candidate to fixate, sequentially both near and far lights. Each eye is then covered in turn. Should the uncovered eye move to take up fixation it denotes a manifest strabismus and the degree and direction of movement denotes its magnitude and type. This can also be detected by observing the position of the reflections of the fixation light on the corneae, normally these are central. Should a manifest strabismus not be present, the movement of the covered eye should be observed both when first covered and then when the cover is removed. If the eye moves in one direction when covered and in the opposite direction when removing the cover it denotes the presence of a latent strabismus or heterophoria, the type and magnitude again being dependent on the direction, excursion and speed of movement.

Heterophorias can be measured using the standard Maddox Wing or Rod Tests for near and the Maddox Rod for far. The convergence ability of the eye is best determined using one of the near point rules. Should a candidate be outside the limits for acceptance he should, at the discretion of the examiner, be subject to an orthoptic review.

The ocular muscle balance should be within the following limits:

Distance: Eso 6cm/m to Exo 6cm/m; hyperphoria not to exceed 1.0cm/m.

Near: Eso 8cm/m to Exo 8cm/m; hyperphoria not to exceed 1.0cm/m.

Convergence: To be 10 cm or less.

Media and Fundi

There should be no evidence of pathology which could impair visual performance either at the time of the examination or in the near future. Any abnormal finding must be assessed by an ophthalmologist experienced in the visual requirements of military aviation.

Visual Fields

The field of each eye should be full. The fields to be measured preferentially on a perimeter or by confrontation.

SPECIALISED EXAMINATION TECHNIQUES

Contrast Sensitivity with Gratings

The standard Snellen Test type presents a high contrast target of black letters on a white background and is a measure of the resolving ability of the eye. Vision in flight involves more than the detection of high contrast detail, it is necessary to distinguish low contrast objects with indefinite outlines against mixed backgrounds. Military air operations are not confined to bright high contrast sunny days, but frequently take place under dull misty conditions and involve close air support of ground operations. In such operations there is often a requirement to detect targets in which camouflage has been used to conceal sharp contours. An aviator who is able to perform well under such conditions is at a definite advantage, Ginsburg (Ref 3).

The technique of measuring contrast sensitivity using sine wave gratings has steadily gained favour and is now in clinical use to detect peripheral retinal disease, Arden (Ref 4). It is a measure of the modulation transfer function of the eye, that is the ability of the eye to perceive contrast at different spatial frequencies - usually in the range 0.2 to 25.0 cycles per degree, the higher spatial frequencies being similar to the range investigated by the Snellen chart. In applying the test the sine wave gratings are produced on a television monitor screen by a grating generator (Fig 1). In short, each spatial frequency to be monitored is presented at zero contrast and the contrast is gradually increased until the candidate is just able to detect the grating pattern which he has previously been shown at high contrast. The test is repeated at different spatial frequencies and a graph plotted of spatial frequency against required contrast for detection. A normal plot of spatial frequency against required contrast is shown in (Fig 2). A simpler form of the test is to use the Arden plates in which the gratings are printed in book form and vary in contrast from the top to the bottom of each page.

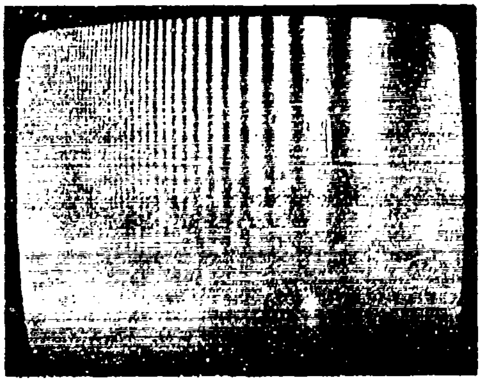

Figure 1. Sine wave grating display with frequencies and contrast swept.

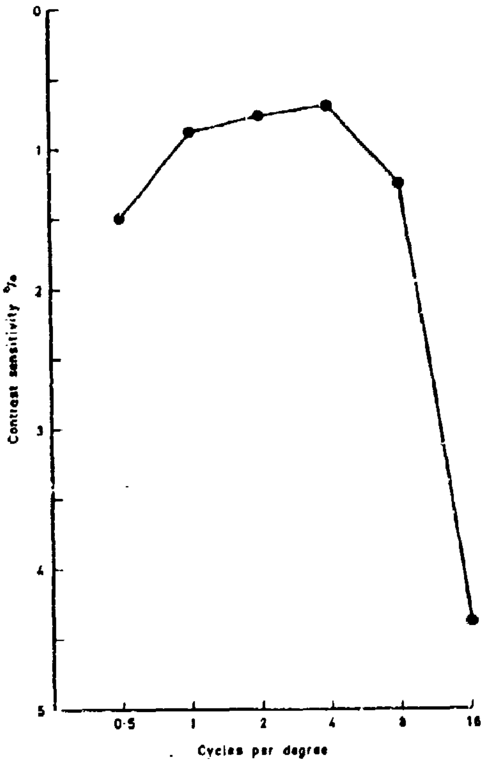

Figure 2. A normal plot of ocular modulation transfer function.

Stereopsis

Depth perception is judged by both monocular and binocular cues. The binocular cue of convergence is of little value by virtue of the short base of the ocular rangefinder but the binocular cue of stereopsis is considered to be the single most valuable depth cue available to aviators. It is the third stage of binocular visual perception, the two previous stages being simultaneous perception and fusion. The essence of stereopsis is that by virtue of the separation of the two eyes dissimilar images, at points which are non corresponding on the horopter, are present at the two foveae and these images can be fused to produce a three dimensional effect. The different appearance of the target as perceived by the right and left eyes is a measure of the instantaneous parallax. The critical values for parallax detection have been variously estimated at between 2 to 24 seconds of arc, which is very accurate corresponding to a difference of less than the diameter of a single retinal foveal cone (1.5-2μm). This allows for depth perception out to distances of about 500 metres. The limiting factor is, again, the small inter ocular separation.

It is, therefore, of great value to assess the stereoscopic ability of aviators. This is routinely evaluated in many, but not all, countries. There are a variety of suitable tests available such as the Verhoeff or Howard Dolman. Stereopsis is not currently, measured in the RAF, but if adopted, scores of 8 out of 8 or 30 mm or better respectively, would probably be acceptable.

Glare Resistance and Dark Adaptation

Fighter pilots are confronted by a variety of glare sources, the commonest being the sun. It has always been standard practice in aerial combat, to position your aircraft relative to your enemy so that he is compelled to look close to the sun and thus suffer a loss of visual acuity. Other glare sources include electrical storms, explosions, strobe lights, ground lights, search lights and that most potent glare source - a nuclear fireball. All these glare sources can profoundly reduce visual acuity, contrast recognition and hue discrimination, the decrement varying between individuals, in part, being related to minor ocular pathology or ametropia. As the eye ages, scatter sources in the media, particularly the lens, multiply, increasing the degradation of the retinal image from intra-ocular glare.

It is desirable to protect aviators from solar glare by tinted visors and by dynamic thermal flash protective devices, such as lead lanthanum zirconate titanate (PLZT), when exposed to nuclear fireballs. Tests for monitoring aviators glare resistance are not yet standardised but, if used, would involve the reading of a test target with an overlying glare source of variable intensity, Wolbarsht (Ref 5).

In modern fighter aircraft where instrument and CRT displays both white and multi-coloured must be interpreted correctly, the panel luminance must be sufficiently bright for cones to function accurately (0.3-3.0 cd/m²). At this level external vision should not be degraded to an extent incompatible with recognising terrain features or other aircraft. It seems unecessary, therefore, to monitor absolute rod thresholds, using adaptometers such as the Goldmann Weekers or Friedmann. Under some circumstances it may be of value to determine the recovery time from being flash blinded to upper photopic levels, to recovery to the cone/rod step junction of the dark adaptation curve.

Hue Discrimination

It is common practice in many services to monitor colour vision by means of pseudo-isochromatic plates such as the Ishihara, lit with the correct illuminant. Should the candidate fail to correctly interpret the plates he is given a 'trade test' which requires that he correctly name the signal colours of red and green and is also able to correctly name white after having been shown 'white'. The test is performed using one of many lanterns such as the Farnsworth, Holmes-Wright, Martin or Giles-Archer. The colours are presented, in a darkened room, at different visual subtenses from a point source upwards. Although the colours are presented randomly and confusional colours are sometimes added, errors occur. There have been occasions when, perhaps by incorrect or hurried application of the tests, personnel have been admitted to flying training who later prove to have an unsafe colour defect. The tests in general usage only monitor red and green defects, they do not monitor blue defects, although it must be stated that tritanomalous individuals are uncommon, being only about 1% of colour defectives.

Fighter aircrew must not only be able to distinguish red and green colours, cockpit arrays, terrain features and ground lights, they must also be able to interpret future generation cathode ray tube (CRT) displays. These displays use both unsaturated hues and blue phosphors. Fig (3) shows the position on the C.I.E. Chromaticity chart of some of the colours which may be used. The co-ordinates of these colours clearly demonstrate the necessity of monitoring blue discrimination when cyan, lilac, blue and magenta hues must be correctly differentiated. Although yellow, amber and brown colours are not monitored by current colour vision tests, these colours are derived, on a CRT, from a combination of the red and green phosphors. They should therefore be accurately interpreted by individuals with normal red/green discrimination.

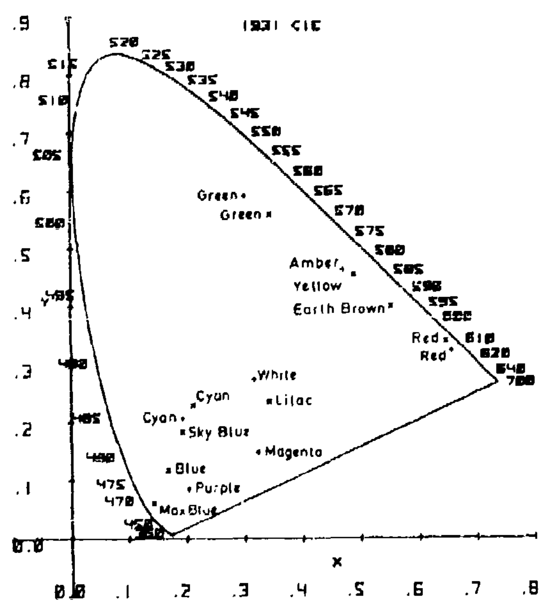

Figure 3. Chromaticity chart illustrating co-ordinates of some hues used in aviation displays.

A test which serves to segregate personnel into high and low categories of hue discrimination is the 'Farnsworth-Munsell 100 Hue Test'. This test requires candidates to sort coloured caps into their natural sequence to form a colour circle and enables the candidates to be scored by monitoring the number and magnitude of their errors. The test was not designed to separate personnel into those who can interpret CRT displays correctly and those who cannot. It may, however, serve that purpose but trials would be necessary. It may be more profitable to design a CRT derived colour vision test specifically to monitor the hues in aviation usage.

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SENSIBILITE AU CONTRASTE EN COULEURS ET SELECTION DU PERSONNEL NAVIGANT

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RESUME

Par une méthode psychophysique particulière (fiable, rapide), la fonction de sensibilité au contraste (FSC) en couleurs est testée systématiquement chez des sujets venant de consultation ophtalmologique. Après une évaluation de cette FSC chez une population emmétrope, diverses amétropies sont étudiées. La constitution du visuogramme quantifie pour chaque déficit les modifications de la FSC. Il existe une altération pour les fréquences spatiales élevées (détails fins) dans la couleur bleu chez les myopes et dans la couleur rouge chez les hypermétropes. Cette altération est proportionnelle au degré d'amétropie. A l'avenir, la mesure de la FSC et la quantification par visuogramme peut être la base d'un test de sélection du personnel navigant (test global de la fonction visuelle).

1. INTRODUCTION - POSITION DU PROBLEME

En aéronautique, la détection de cibles met en jeu des contrastes très variables et faibles entre les différentes parties d'une scène visuelle. Peu de tests de sélection ophtalmologique interrogent ces contrastes faibles. Quand on mesure l'acuité visuelle (lettre noire sur fond blanc), le contraste est maximum et non variable. Seule la fonction de sensibilité au contraste permet facilement cette mesure. L'intérêt essentiel de la fonction de sensibilité au contraste (FSC) de luminance est l'exploration de détails visuels dont les contrastes sont très faibles. La FSC est un examen couramment pratiqué dans les laboratoires de recherche sur la vision. Elle utilise le principe que toute scène visuelle peut être décomposée en ses diverses fréquences spatiales. En utilisant des fréquences spatiales dont le profil de luminance est sinusoïdal, on peut chez l'homme par des méthodes psychophysiques caractériser la FSC en monochrome. GINSBURG (5) a été un des pionniers de l'utilisation de la FSC en aéronautique. De plus, selon cet auteur, il existe une bonne corrélation entre la détection de cibles et les caractéristiques de la FSC monochrome.

En 1982, SEKULER et Coll. (12) montrent l'intérêt d'une telle méthode dans les tests aéronautiques, et ils notent les différentes voies de recherches. Ils proposent cet examen dans la batterie de tests ophtalmologiques. Parallèlement, des auteurs comme HYVARINEN (7), COMERFORD (3), ARDEN (1), FIORENTINI et MAFFEI (4) ont utilisé la mesure de la FSC dans le dépistage de pathologies de la voie visuelle. COMERFORD peut ainsi conclure sur le type de déficit visuel en fonction de l'atteinte dans les fréquences spatiales (anomalies de réfraction, névrite rétrobulbaire...). Cependant, excepté un petit nombre d'études dont celles de KELLY (8), COURDY et Coll. (2), MENU et SANTUCCI (10), la couleur n'est pas un paramètre couramment pris en compte dans l'étude de la sensibilité au contraste.

Or, l'utilisation de la couleur en aéronautique est un fait incontestable comme en témoignent les cockpits des aéronefs les plus modernes tant civils que de combat. Les concepteurs de ces systèmes définissent les couleurs en assumant que le pilote présente une vision des couleurs normales. Or, indépendamment des dyschromatopsies, de nombreuses anomalies visuelles peuvent avoir un retentissement sur la vision de symboles colorés.

Il faut noter que tous les examens de dépistage d'anomalies de la vision des couleurs mettent en oeuvre des tests où la couleur n'est pas supportée par une forme représentative de celles qui peuvent être rencontrées en aéronautique. De plus, les stimulations colorées sur de tels systèmes sont des sources primaires émissives. La plupart des tests de dépistage des anomalies de la vision des couleurs sont la plupart basés sur des sources secondaires pigmentaires. Des tests dont le support est un tube cathodique couleurs, sont alors des moyens plus proches des situations couramment rencontrées sur les tableaux de bord électroniques.
Tous ces faits ont motivé des travaux concernant la FSC en couleurs. L'étape rapportée ici concerne l'établissement de courbes de FSC chez les sujets normaux et l'effet des petites amétropies sur celles-ci.

Cependant avant d'exposer ces principaux résultats, il nous faut avant tout présenter les caractéristiques essentielles d'un test de sélection visuel et la méthodologie utilisée pour obtenir la FSC couleurs des différents patients.

2. CARACTERISTIQUES D'UN TEST DE SELECTION VISUEL

Un test de sélection a comme finalité première de vérifier si le candidat à un travail particulier a bien les aptitudes pour effectuer la tâche. A un deuxième degré, si les candidats sont trop nombreux, il doit autoriser le choix de ceux possédant les meilleures caractéristiques. Le test de sélection doit donc répondre à un certain nombre de critères :

- Tester une fonction pertinente pour la tâche considérée. La fonction de sensibilité au contraste permet d'évaluer les performances du sujet en matière de détection de contrastes de valeurs différentes. Un des paramètres de détection d'un avion dans le ciel est fondamentalement le contraste de cette cible sur le ciel. C'est une tâche de type classe 2 dans la classification établie par SEKULER (12),

- Le test de sélection doit être fidèle, c'est-à-dire donner les mêmes résultats pour des sujets ayant les mêmes caractéristiques physiologiques ou pour un même sujet. La corrélation est alors à faire avec des batteries d'autres examens caractérisant la fonction visuelle,
- Il doit être sensible et autoriser des discriminations très fines,
- Il ne doit pas prendre trop de temps,
- Par ailleurs, en dehors de ces caractéristiques essentielles, propres à un test quelconque de dépistage, un test de sélection visuel pour pouvoir atteindre une certaine diffusion et par là même une utilisation courante, doit être de manipulation aisée par l'expérimentateur et donner des résultats facilement utilisables et exploitables pour le médecin.

3. METHODOLOGIE

3.1. PRINCIPE GENERAL

La mesure de la FSC rapportée dans ce travail met en jeu des méthodes psychophysiques. Ces méthodes sont le moyen le plus rapide de mesure de la FSC. Les mesures objectives sont en effet diffficiles à manipuler, utilisant l'éléctrophysiologie, et outre le temps d'examen, leur reproductibilité n'est pas assurée.

Quoiqu'il en soit, quelle que soit la méthode utilisée, le terme fonction de sensibilité au contraste doit être explicité. En effet, sous le même terme, selon les auteurs et les laboratoires, des éléments variés de la stimulation visuelle sont étudiés. Les fonctions de sensibilité au contraste sont multiples, selon les éléments de la stimulation que l'on fait varier (couleur, fréquence spatiale, fréquence temporelle, excentricité dans le champ visuel, stimulation stable ou en mouvement). Ainsi bien que souvent la stimulation élémentaire soit une alternance de bandes claires et sombres (les réseaux), ces réseaux peuvent être présentés de manière stable ou en mouvement, en couleur ou en monochrome, en vision centrale ou en vision périphérique. Ici sera seule étudiée la fonction de sensibilité au contraste, en vison centrale, pour des réseaux colorés stables.

3.2. LA STIMULATION

Des réseaux sinusoïdaux stationnaires rouges (x = 0.674, y = 0.296), verts (x = 0.375, y = 0.544), bleus (x = 0.144, y = 0.069) sont présentés verticalement ou horizontalement sur des tubes cathodiques couleurs haute résolution dont la fréquence de rafraichissement est de 50 Hz. Douze fréquences spatiales, 6 verticales et 6 horizontales de 0.01 cycle/degré à 13,5 cycles/degré, ont été testés.

La luminance moyenne est de 40 cd/m2. La valeur du contraste est obtenue à partir de la formule de MICHELSON :

$$C = \frac{Lmin - Lmax}{Lmin + Lmax}$$

En effet, pour obtenir ce contraste, on module la luminance de la stimulation entre une luminance maximum et une luminance minimum de part et d'autre de la luminance moyenne.

3.3. METHODES PSYCHOPHYSIQUES

Deux méthodes psychophysiques ont été évaluées successivement afin d'établir un choix répondant au mieux aux critères des tests définis précédemment.

3.3.1. Méthode d'ajustement automatique

Dérivée de la méthode d'ajustement montant classique décrite, elle avait été mise au point pour une étude fondamentale de la FSC (MENU et SANTUCCI (10)). L'accroissement du contraste à partir de la valeur 0 est automatique, piloté par le calculateur. Le pas d'incrément est de 0,0025.

Le sujet répond avec un levier dès qu'il perçoit le réseau. Il donne l'orientation, verticale ou horizontale en poussant le levier dans le sens du réseau perçu.

3.3.2. Méthode dichotomique

C'est une méthode à choix forcé. Elle est dérivée des méthodes de double escalier psychophysique. Parfaitement adaptée à un examen piloté par ordinateur, elle permet en 10 présentations de contraste différent (figure 1) de définir le seuil pour une fréquence spatiale. A l'origine, elle fut retenue pour pouvoir contrôler le temps de présentation du test. Par ailleurs, elle permet un examen plus rapide que la méthode d'ajustement.

3.4. ANALYSE DES DONNEES

3.4.1. Courbes de sensibilité

A partir des valeurs seuil de contraste obtenues pour chaque fréquence spatiale, la représentation des données la plus courante est la courbe de sensibilité au contraste exprimée en coordonnées log-log en fonction des fréquences spatiales. Cela consiste à positionner les valeurs brutes de seuils.

3.4.2. Les visuogrammes

Une deuxième analyse apporte des résultats exploitables plus facilement pour l'ophtalmologiste. Elle permet de plus en plus une quantification des données par rapport à une référence. La différence entre les seuils des diverses fréquences spatiales. L'atténuation ou le gain par rapport à cette population normale est calculée pour chaque fréquence spatiale selon la formule :

$$G = 10 \log \frac{Cs}{Cr}$$

Cs contraste du sujet
Cr contraste de la population de référence

En accord avec LUNDH et ARLINGER (9), c'est le visuogramme (figures 4 et 5).

Cette pratique offre l'avantage d'une quantification immédiate du déficit exprimé soit en décibels, soit en pourcentage d'atténuation par rapport à la normalité. C'est actuellement cette analyse qui nous semble la plus intéressante dans le cas d'un test de sélection dépistage.

3.4.3. Expression des résultats

Dans l'expression des résultats, nous mentionnerons respectivement les deux techniques. La première donne des valeurs absolues de seuil ; la seconde des valeurs relatives.

3.5. LA POPULATION ETUDIEE

Tous les sujets examinés ont subi un examen ophtalmologique clinique et les épreuves fonctionnelles pour la vision des couleurs, vision binoculaire, vision nocturne, etc...

En effet, ce sont des pilotes ou des candidats pilotes. Chaque fois, une skiascopie sous cycloplégique a été pratiquée pour déterminer la réfraction des sujets. Ainsi, en fonction de ces données, trois populations sont distinguées :

- Les sujets dont la fonction visuelle est normale dans tous ses éléments. Ils sont emmétropes,
- Les sujets dont la fonction visuelle est normale excepté une amétropie banale,
- Les sujets présentant des pathologies diverses.

4. RESULTATS

4.1. COMPARAISON DES DEUX METHODES D'EXAMEN

Cette étude a donné lieu à une publication soumise à approbation dans Investigative Ophtalmology and Visual Science. Elle a montré que la méthode pas à pas était parfaitement adaptée à la finalité exposée ici à savoir la sélection. Elle est fidèle chez un même sujet, des examens répétés donnant les mêmes seuils. Elle est plus vraie que la méthode d'ajustement car les sensibilités au contraste observées sont plus élevées qu'avec la méthode d'ajustement.

Elle est plus rapide car les sensibilités au contraste pour un oeil et pour trois couleurs sont recueillies en 15 minutes.

4.2. COURBES DE SENSIBILITE AU CONTRASTE

4.2.1. Courbe de référence - population emmétrope

A partir des données recueillies sur 16 sujets emmétropes, on peut tracer une courbe de sensibilité dite "témoin". Elle est indiquée sur les figures 2 et 3. Sur ces figures, la valeur moyenne du contraste pour chaque FS est matérialisée ainsi que la dispersion de 1 écart-type autour de cette valeur moyenne.

- D'emblée, il est intéressant de remarquer que l'optimum de sensibilité est situé pour les 3 couleurs à 2 cycles/degré pour les réseaux verticaux.
- La couleur verte est globalement mieux vue que le rouge et le bleu qui sont très proches l'une de l'autre.
- La dispersion des données est voisine pour chaque fréquence spatiale d'une couleur à l'autre.

Les résultats de chaque sujet, adressé par l'ophtalmologiste, peuvent être positionnés sur la courbe, par rapport aux valeurs de la population témoin. Cela permet d'avoir une première évaluation de la fonction visuelle et de déficits particuliers s'ils existent.

3.4.2. Courbes de sensibilité des sujets amétropes

Après l'examen de plus de 100 amétropies diverses, les résultats les plus importants et les plus nets sont les suivants :

- Il existe une diminution de la FSC au bleu dans les hautes fréquences spatiales pour des sujets myopes. La coupure haute est décalée vers la gauche.
- La FSC au rouge est diminuée dans les hautes fréquences spatiales pour des sujets hypermétropes.
- Des astigmatismes présentent une asymétrie vertical-horizontal beaucoup plus marquée que la population "normale".
- Associé à cette altération dans les hautes fréquences, l'optimum de sensibilité est abaissé et décalé dans les fréquences spatiales plus basses (passage de 2 à 1 cycle/degré). En somme, l'altération ne touche pas uniquement les hautes fréquences mais aussi les fréquences moyennes dont la discrimination du contraste est diminuée.

4.3. COURBES D'ATTENUATION - VISUOGRAMMES

4.3.1. Visuogrammes des emmétropes

A partir des résultats bruts sur les différents sujets emmétropes, il a été possible d'établir des limites d'atténuation en fonction des fréquences spatiales pour chaque orientation et chaque couleur. Ce sont ces limites qui sont indiquées sur les courbes d'atténuation des figures 4 et 5.

La ligne la plus proche de l'axe des fréquences spatiales, en trait plein, indique la limite des valeurs d'atténuation pour 1 écart-type et 2 écarts-types. On pourra donc considérer que toute valeur inférieure à cette 2ème zone est hors de la zone de normalité. Plus la valeur d'atténuation sera éloignée de cette zone, plus le déficit sera important. Une quantification est possible à partir de la valeur même de cette atténuation exprimée en décibels.

4.3.2. Visuogrammes des amétropes

Les figures 4 et 5 indiquent pour les myopes forts (plus de 4 dioptries) et les hypermétropes, ces visuogrammes pour les couleurs bleu et rouge.

- Pour les myopies faibles (inférieures à 2 dioptries), le déficit intéresse pour la couleur bleu exclusivement les fréquences spatiales élevées. Les fréquences moyennes et basses (inférieures à 1 cycle/degré) ne sont pas modifiées. Pour les couleurs vert et rouge, cette atténuation des fréquences élevées ne dépasse pas la limite de 2 écarts-types.

- Pour les myopies fortes (supérieures à 2 dioptries) et la couleur bleue, seule la plus basse fréquence spatiale n'est pas altérée. L'atténuation est ensuite d'autant plus forte que l'on augmente les fréquences spatiales. Une atténuation de plus de 10 db existe même pour les fréquences les plus élevées. Les visuogrammes des couleurs vert et bleu sont beaucoup moins perturbés.

- Le visuogramme pour la couleur rouge des sujets hypermétropes est représenté sur la figure 5. Pour cette couleur rouge exclusivement, on trouve une atténuation des fréquences spatiales élevées. En-dessous de 1 cycle/degré, il n'existe pas de modification de la FSC. Pour les couleurs bleu et vert, les hypermétropes ne présentent pas cette altération. Cette altération globale moins nette que pour les myopes peut s'expliquer en partie par le fait que ces hypermétropes testés présentaient des déficits moins importants (inférieurs à 2 dioptries).

4.4. RESULTATS SUR DES PATHOLOGIES OPHTALMOLOGIQUES

Bien que présentés en dernier ici, ces résultats ont été obtenus en premier. Cent pathologies ophtalmologiques diverses ont eu une mesure de la FSC couleurs par la méthode d'ajustement montant automatisée. De par l'existence de pathologies, les déficits de la FSC sont beaucoup moins systématisés sur une couleur et pour les diverses fréquences spatiales. Cependant, les résultats les plus pertinents concernaient les amétropies associées à une pathologie. Les myopes présentaient un déficit pour le bleu dans les hautes fréquences spatiales alors que c'était pour le rouge chez les hypermétropes. C'est pour cette raison que lors de la deuxième étude, les amétropies ont été systématiquement étudiées sur une population globale la plus homogène possible.

5. DISCUSSION

Deux niveaux doivent être distingués : la méthodologie elle-même et les principaux résultats.

5.1. SUR LA METHODOLOGIE

Au cours des enregistrements successifs de la FSC couleurs avec les différentes méthodes psychophysiques, la méthode dichotomique pas à pas est celle qui apporte les résultats les plus cohérents, les plus précis et les plus fiables. De plus, elle apporte des résultats facilement exploitables pour un temps d'examen court (moins d'une demi-heure pour les 3 couleurs primaires). Avec cette méthode, la succession des images au sein d'une série expérimentale, avec l'introduction entre chaque image test coloré d'une image blanche au même niveau lumineux, évite l'épuisement ou la sidération du type de photorécepteur interrogé. La gamme des fréquences spatiales utilisées est étendue, couvrant un domaine qui n'est pas toujours exploré au sein d'un même examen.

L'utilisation de tubes cathodiques couleurs assure une standardisation et une calibration dans les caractéristiques physiques de la stimulation visuelle, ce que les tests papiers comme les planches d'ARDEN ou VCI CHART ne peuvent assurer. Le champ du tube couvre 8 degrés et permet d'interroger globalement toute la vision centrale. Intégré dans un environnement contrôlé, il assure une calibration et une stabilité de la stimulation visuelle.

Tous ces éléments en font un test fiable, facile à mettre en oeuvre, pour des sujets naïfs "tout venant" de consultation ophtalmologique. Son temps de passation relativement court n'est pas pénalisant pour l'intercaler dans une batterie d'examen dans le cadre d'une sélection ou d'un dépistage d'anomalies de la fonction visuelle.

On peut attribuer cela au fait que la présentation utilisée ne comporte pas qu'une seule couleur et que l'examen lui-même dure un temps négligeable. Le sujet ne peut donc pas compenser un petit déficit latent pendant toute la durée de l'examen. La méthodologie sensibilise le petit défaut de réfraction.

La diminution de sensibilité aux hautes fréquences pour le bleu chez les myopes et le rouge pour les hypermétropes, est sans doute liée en majeure partie à l'aberration chromatique de l'oeil. Le bleu convergeant en avant du plan rétinien sensibilise une myopie latente. L'hypermétrope quant à lui verra moins bien le rouge puisque ce dernier converge en arrière du plan rétinien.

On peut avec la méthode de mesure pas à pas de la FSC couleurs, parler véritablement de test de sélection du personnel navigant. Les courbes indiquent l'état fonctionnel de tout le système visuel. D'après la remarque précédente, la couleur est un élément essentiel puisque la FSC en noir et blanc ou en monochrome vert n'aurait pas pu être aussi fine et indiquer de petits déficits latents.

Cependant, un grand nombre de sujets différents doit être passé afin d'établir une véritable étude épidémiologique des fonctions de sensibilité au contraste. Elle devient alors essentiellement un problème intime entre chercheurs et cliniciens, mais aussi un problème de temps d'examen afin de constituer les différents groupes de référence.

5.2. SUR LES PRINCIPAUX RESULTATS

Outre l'intérêt global de la FSC déjà montré par ailleurs (GINSBURG, SEKULER), l'intérêt de la couleur dans la mesure de la FSC est mis en évidence par certains résultats.

Même chez les emmétropes, il existe une meilleure perception pour la couleur verte. Si la courbe "témoin" n'a été établie que sur 16 sujets, celà tient à plusieurs faits. Nous n'avons retenu pour l'établir que des sujets présentant des courbes de sensibilité parfaites, sans aucun point "aberrant". Par ailleurs, certains sujets voyaient parfaitement l'écran. Placés à 1,30 mètre de celui-ci, ils pouvaient se trouver gênés par la trame télévision et répondaient plus à cette trame qu'aux réseaux présentés. En quelque sorte, possédant une acuité visuelle très élevée, malgré la présentation des différents types de réseaux avant l'expérimentation, ils répondaient à la trame du moniteur et non à ces réseaux. A l'avenir, un nouveau compromis distance de vue du tube, angle de vision de ce tube, gamme de fréquences spatiales devra être trouvé afin d'éliminer cet effet pour les sujets emmétropes.

Dans certains cas d'amétropies, les courbes de FSC pour le rouge et le bleu ne sont pas similaires à celles du vert.

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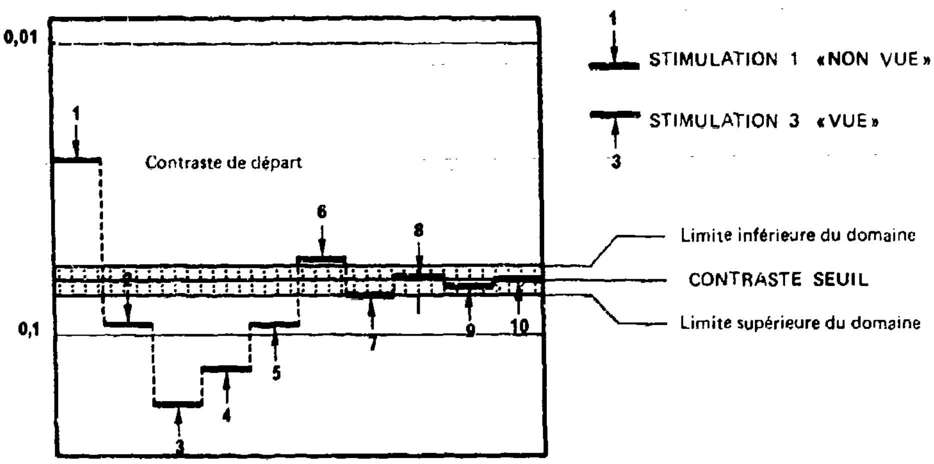
FIGURE 1



FRÉQUENCE SPATIALE : 0.2 cycle/degré
CONTRASTE SEUIL : 0.06
VALIDITÉ : Élevée

ÉVOLUTION DES RÉPONSES ET CONTRASTES PRÉSENTÉS A UN SUJET POUR LA FRÉQUENCE SPATIALE DE 0.2 CYCLES PAR DEGRÉ. LES LIMITES INFÉRIEURES ET SUPÉRIEURES DU DOMAINE AINSI QUE LE SEUIL RETENU ET L'INDICE DE VALIDITÉ SONT INDIQUÉS.

FIGURE 2

VALEURS DES SEUILS DE SENSIBILITE AUX CONTRASTES POUR LES TROIS COULEURS PRIMAIRES ROUGE, VERT, BLEU,
A LA LUMINANCE MOYENNE DE 40 CANDELAS PAR METRE CARRE.

– VISION CENTRALE.
– RÉSEAUX VERTICAUX.

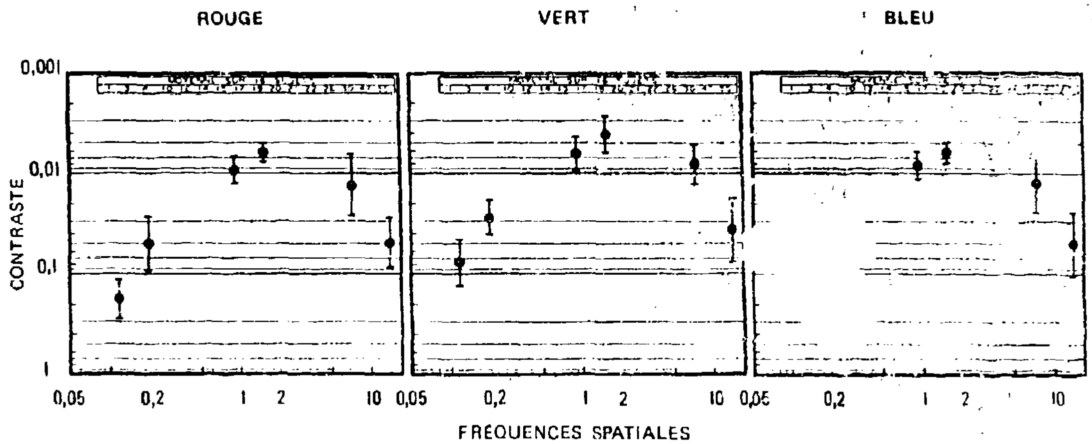
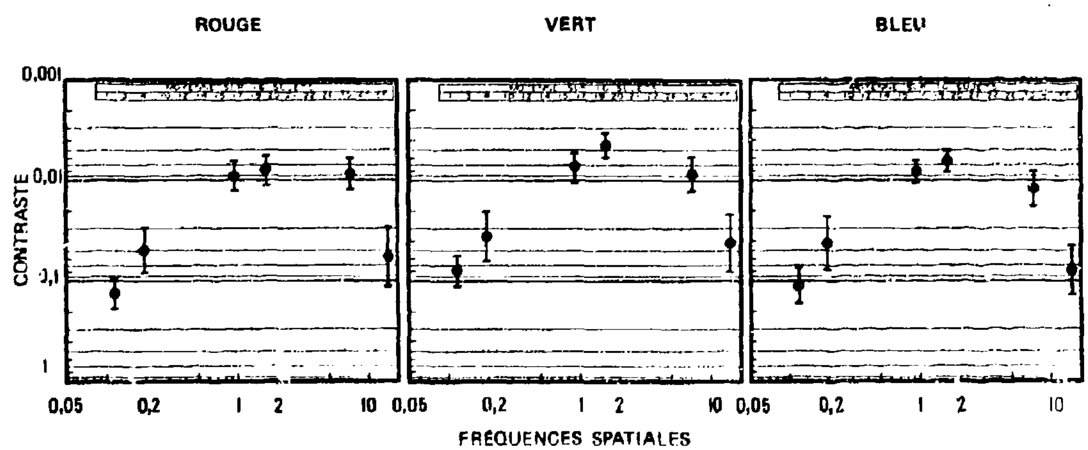


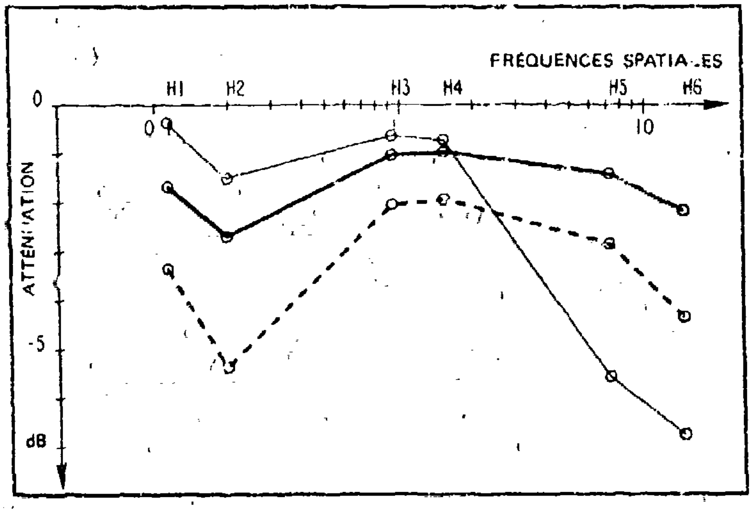
FIGURE 3

VALEURS DES SEUILS DE SENSIBILITÉ AUX CONTRASTES POUR LES TROIS COULEURS PRIMAIRES ROUGE, VERT, BLEU,
A LA LUMINANCE MOYENNE DE 40 CANDÉLAS PAR METRE CARRÉ.

– VISION CENTRALE.
– RÉSEAUX HORIZONTAUX.

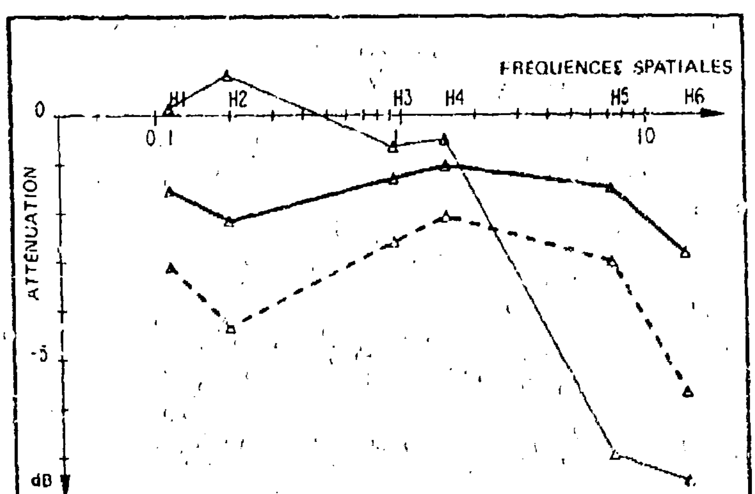


—— courbe moyenne d'atténuation des sujets amétropes
—— limite de 1 écart type pour la population emmétrope
- - - limite de 2 écarts types pour la population emmétrope



ÉVOLUTION DE L'ATTÉNUATION POUR LES DIVERSES FRÉQUENCES SPATIALES, LA COULEUR BLEU CHEZ DES SUJETS MYOPES.

FIGURE 4



EVOLUTION DE L'ATTÉNUATION POUR LES DIVERSES FRÉQUENCES SPATIALES, LA COULEUR ROUGE, CHEZ DES SUJETS HYPERMÉTROPES.

FIGURE 5

COMPUTER ANALYSIS OF VISUAL AND VESTIBULAR OCULOMOTOR FUNCTION IN THE MEDICAL SELECTION OF FIGHTER AIRCREW MEMBERS

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SUMMARY

This paper reviews methods for evaluating visual and vestibular-oculomotor function in aircrew members. Three specific tests are described: (1) pursuit tracking, (2) harmonic angular acceleration, and (3) saccadic tracking. In all of these tests, on-line computer analysis is used to quantify and describe the input/output relationships. An example of clinical data from pursuit tracking and harmonic angular acceleration tests for a patient with known pathology are used to demonstrate changes in test results. The major point of this paper is that it is now practical to evaluate oculomotor function in pilots and aircrew members selected for fighter aircraft duty.

It is obvious that vision and visual-vestibular oculomotor control are critical sensory systems in air-to-air operations, and that fighter pilots differ in their abilities to acquire and track targets. Therefore, it would appear important to determine if oculomotor performance may be a relevant factor in determining these differences. Furthermore, if a model can be developed that characterizes the distinguishing features of oculomotor performance for the superior pilot, it may be possible to train all pilots to improve their ability to process visual input in a dynamic environment.

Within the past decade, a number of quantitative tests of oculomotor-vestibular function have been developed (1,2,3,4). Two of these procedures, a test of pursuit tracking and one using harmonic angular acceleration, have also become commercially available and are presently being conducted at over 40 medical centers worldwide. As a result, a large body of normative and clinical data now exists for these particular tests. Within the United States military, only Brooks Air Force Base and Wilford Hall USAF Medical Center have developed or acquired the capability to perform these tests. Recently, the Neurosciences Function at USAFSAM has also developed the methodology for totally characterizing the saccadic (fast) eye movement system. These three tests (pursuit tracking, harmonic angular acceleration, and saccadic tracking) can be accomplished in approximately 1 -1.5 hours. The final product is a comprehensive and quantitative description of individuals' visual-vestibular-oculomotor system.

It is the purpose of this paper to show that if such information were available for all pilots and aircrew members selected for fighter aircraft duty, longitudinal studies could be accomplished and these variables correlated with performance. In addition, a standard would be available to determine if clinical pathology is developing related to these systems.

RATIONALE OF OCULOMOTOR EVALUATION

Since visual and vestibular-oculomotor function use common neurological pathways, both systems require precise quantitative processing of sensory input in order for the individual to acquire and process visual information. It is well known that the visual oculomotor system is a low frequency system which functions in the range from DC to approximately .5 Hz, whereas the vestibular oculomotor system is a high frequency system and can provide a stabilized retinal image from .1 - 5 Hz. Therefore, if a target moves at a velocity exceeding 50°/s the average individual will be unable to properly track the target unless he generates "catch-up" saccades. If, in addition, he is also being subjected to either high level angular or linear accelerations, his static and dynamic visual acuity will be compromised by the interactive effects of vestibular nystagmus and counter-rolling of the eyes. An extreme case, is the departure from flight which can occur in swept-wing high performance aircraft. In the case of the F-15, "The aircraft can transit from intentional, controlled roll rates in excess of 180°/s almost instantaneously (5)". In this situation, it would be functionally impossible to process any spatial visual information. Since pilots are being exposed to acceleration environments which exceed the dynamic range of the oculomotor system, it would appear imperative to determine the parameters of visual and vestibular-oculomotor function in these individuals.

METHODS OF EVALUATING PURSUIT TRACKING

Most laboratories generate a visual target by deflecting a collimated beam of light from a low-power laser off a mirror galvanometer. In our case, the target is a spot of red light (632.8 nm) subtending visual angle of 15' at the cornea. The spot is reflected onto a rear projection screen and deflected ± 10° in the horizontal plane in order to obtain calibration signals for both the individual eye and summated eye position electro-oculographic (EOG) signals. Eye movements, in response to sinusoidal target motion, are obtained for three viewing conditions: (1) both eyes tracking, (2) left eye tracking and (3) right eye tracking. Eye movement signals are then fed to a PDP-11/34 digital computer for on-line data analysis. Using auto- and cross-power spectral techniques, gain, phase and spectral purity are calculated for each eye as well as for the summated record for each of the three stimulus condition. This results in a set of nine measures for each stimulus condition. Since [illegible] was difficult to interpret the data in numerical form, a three-axis pictorial plot was developed to display the data in such a manner that a plot of perfect tracking results in an equilateral triangle. Gain is the amplitude of the eye position signal compared to the amplitude of the target displacement, while phase is the time relationship between eye and target position; these two measures are fairly easy to understand. However, spectral purity appears to be a more confusing term. An example of a spectrally

pure stimulus for other sensory modalities would be monochromatic light or a pure-tone stimulus, since in the frequency domain, all of the stimulus power is at a single frequency. The measure, spectral purity, is the ratio of the output power at the stimulus frequency to the total output power. For example, if a target is moving sinusoidally at .4 Hz and the eyes track exactly at this frequency, then 100% of the response is at the input frequency and the ratio of the output power at the stimulus frequency to the total output power would equal one. It follows that output power at frequencies other than the input frequency will lead to a decrease in spectral purity. This distortion is typically due to the eyes tracking in a saccadic rather than a smooth manner. Originally we performed a parametric study with 21 normal male subjects using single frequencies from .2 - 1.6 Hz. These stimuli had peak velocities ranging from 12.5 - 100.5°/s and peak accelerations from 15.8 - 1,011°/s^2. The important finding was that some subjects could track the target almost perfectly at the highest frequency tested (3). It became clear that all normals could adequately track a target moving at .4 Hz and this stimulus frequency was adopted as a standard for clinical evaluations. Figure 1 shows the data plots from 21 normal subjects.

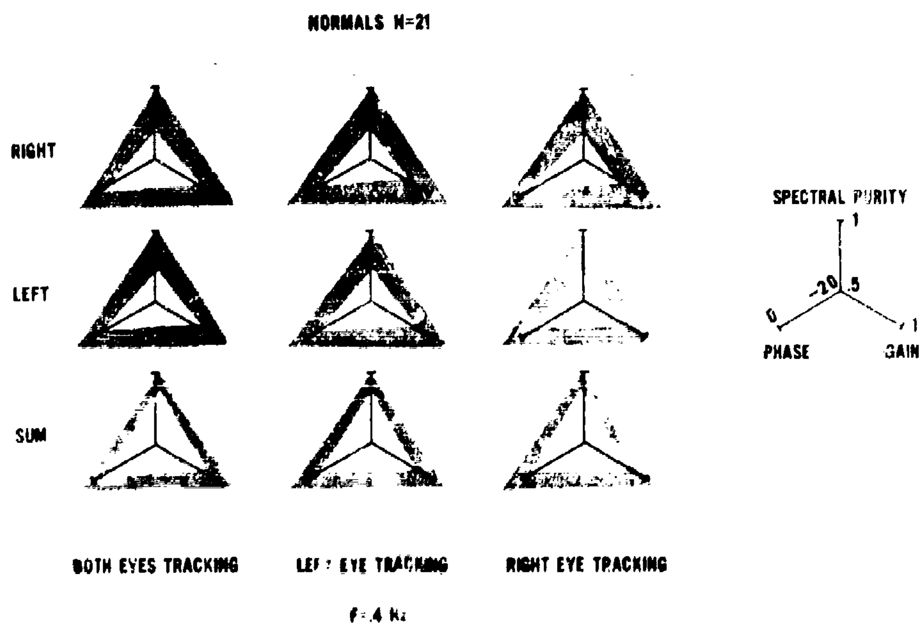

Figure 1. Pictorial plots of pursuit tracking data, F = .4 Hz. Shaded area equals 10th and 90th percentiles for 21 normal subjects. (From Reference 2, reprinted by permission of Annals Publishing Co., St. Louis, MO, 1984)

During the past 6 years, we have evaluated over 2000 carefully selected patients referred by board certified otolaryngologists, neurologists, and neuro-ophthalmologists from the USAFSAM Aeromedical Consultation Service and Wilford Hall USAF Medical Center. The majority of these patients were referred for evaluation of peripheral pathology related to inner ear function. Fortunately, we were able to test many of those patients before and after surgical procedures such as the removal of acoustic neuromas or endolymphatic shunt procedures; and a few selected patients were evaluated annually for up to 6 years postoperatively. Figure 2 shows tracking data from a patient who had a moderate size (2 - 2 1/2 cm) pontine angle tumor. The patient had sought medical advice in response to an apparent decrement in hearing in his right ear. Although he had no vestibular symptoms, caloric testing revealed a 30% unilateral weakness on the right side; however, rotational test results were within normal limits. His pursuit tracking showed a significant decrement in spectral purity and phase relationships were in error when tracked with his right eye. At the time of surgery, the tumor was found to be attached to the brain stem just below the V cranial nerve and it was compressing the pons. When tested 1 week post-surgery, his pursuit tracking still showed a decrement in spectral purity when tracking with the right eye and there was an increase in the gain of his eye movements especially with both eyes tracking. However, the phase relationships when tracking with the right eye were now within normal limits. Figure 2 shows he had almost perfect tracking under all conditions when tested 5 months post-surgery. This case clearly shows the importance of evaluating pursuit tracking monocularly in order to reveal either congenital or pathological asymmetries of the oculomotor system.

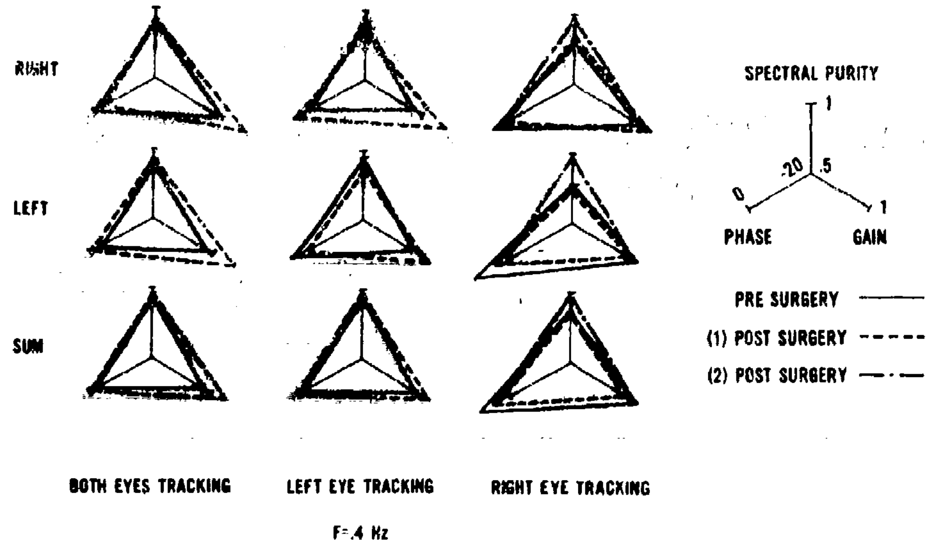

Figure 2. Pre and Post surgical tracking data from a patient with a 2 - 2.5 cm right acoustic neuroma. (1) 1 week post surgery; (2) 5 months post surgery. (From Reference 2, reprinted by permission of Annals Publishing Co., St. Louis, MO, 1984)

METHODS OF EVALUATING SEMICIRCULAR CANAL FUNCTION WITH HARMONIC ANGULAR ACCELERATION

Although rotational testing (angular acceleration) has been used for many years in attempts to evaluate horizontal semicircular canal function, adequate techniques were not available to quantify the relationships between the input and output. With the introduction of reliable DC torque motor driven turntables and the application of digital computers to frequency domain analysis, it became possible to apply more sophisticated techniques in the evaluation of semicircular canal function. As most people are aware, the function of the semicircular canals is to provide an input to the oculomotor system such that the eyes are driven in a compensatory manner in response to angular acceleration of the head. Ideally, eye velocity and head velocity are equal and opposite (180° out of phase) leading to a stabilized retinal image. As previously mentioned, the vestibular system is a high frequency system (.1 - 5 Hz) and complements the visual pursuit system. However in order to eliminate the influence of vision on the oculomotor system, vestibular testing is conducted in the dark.

Since the normal semicircular canal - vestibulo-oculomotor system is a linear system, it is practical to evaluate it with linear system analysis techniques. As in the case of pursuit tracking, the same variables of gain, phase and spectral purity are of primary interest. In addition, since sinusoidal acceleration is symmetrical around zero, it is possible to measure the left-right asymmetry of the vestibulo-ocular reflex (VOR). Rotational testing as developed at USAFSAM involves two options: either single sinusoids ranging in frequency from .01 - .16 Hz or a sum of sinusoids from .01 - .27 Hz are used as stimuli. In our earlier studies (6,7,8) we were able to show that even with the loss of one labyrinth, the VOR was within one standard deviation of the normal range at .16 Hz. However, at lower frequencies phase shifts showed a significant deviation from the normal values (see Figure 3). The data of Figure 3 are from the same patient discussed under "pursuit tracking". Since this patient was stationed at USAFSAM for over 3 years, it was possible to repeatedly evaluate him. Furthermore, as previously mentioned, prior to surgery he had no symptoms other than a unilateral hearing loss; was reasonably young (40 years old), in good health, and very active in sports. Prior to surgery, his tested phase relationships were at the normal mean values above .04 Hz and showed a slight deviation from the normal mean values at .01 and .02 Hz but were still within normal statistical limits. He also had an average directional preponderance of 10% to the left which is within one standard deviation for normal subjects. The sudden loss of one labyrinth due to sectioning of the VIIIth nerve during tumor removal, leads to dramatic changes in the VOR in those individuals who still have considerable horizontal canal function prior to surgery. As shown in Figure 3, one week after surgery this patient's phase relationships were still normal at .16 Hz. However, as the stimulus frequency decreased below .16 Hz his responses deviated over two standard deviations from the normal means. At this period in time he

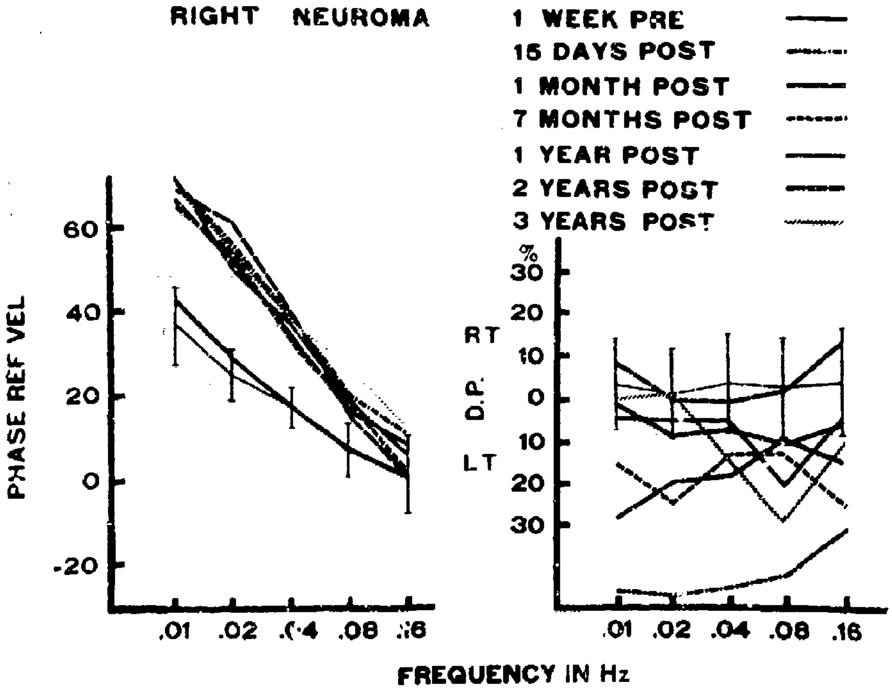

Figure 3. Data from the same patient before and after tumor removal in response to harmonic angular acceleration. (From Reference 8, reprinted by permission of Academic Press, New York, NY, 1984)

also had a 50% preponderance to the left. Although his responses to rotation became symmetrical with time, the phase deficits were permanent. Unfortunately, 1 week prior to his 3-year post surgical evaluation he suffered a severe retinal detachment in the right eye. As shown in Figure 3, this was reflected as an increase in deficit of his phase measures at .08 and .16 Hz and a loss of response symmetry. These results imply that compensation is an active process requiring binocular visual input. The phase measures show the least variability between subjects and within subjects, and were repeatable within a few degrees. Thus, the major advantage of this type of testing is the ability to determine changes in the VOR. Although the phase measures are correlated with pathology, they are also normally distributed; therefore, it would be ideal to have a standard test for all aircrew members in order to determine early loss of function as reflected in subsequent testing.

EVALUATION OF SACCADIC (FAST) EYE MOVEMENTS

Since the generation of saccadic eye movements is under both cortical and reflex control the movements reveal aspects of the oculomotor system that are complementary to the slow pursuit and VOR systems. Our present test uses binocular infrared reflectance techniques to acquire the eye movements and analysis of these data is performed on-line by computer. Eye movements are recorded binocularly for three tracking conditions: left eye tracking, right eye tracking, and both eyes tracking. Target motion is in discrete jumps ranging in amplitude from 5° to 40°, and both the time of the move and its amplitude are randomized.

Eye velocity is calculated from the eye position signals and the resulting records are scanned by the computer to locate all saccadic eye movements made in response to each target displacement. Saccade amplitude, peak velocity, peak acceleration, peak deceleration, duration, and latency are calculated for each eye movement. The functional dependence of these variables on either target amplitude (latency and saccade amplitude) or eye movement amplitude (velocity, acceleration, deceleration, and duration) are determined by regression analysis. A nonlinear regression is used to represent the peak velocity, peak acceleration, and peak deceleration relationships. Data are analyzed for each eye separately and further divided into abducting and adducting movements. The results of these analyses are presented in graphic form to aid interpretation (see Figure 4).

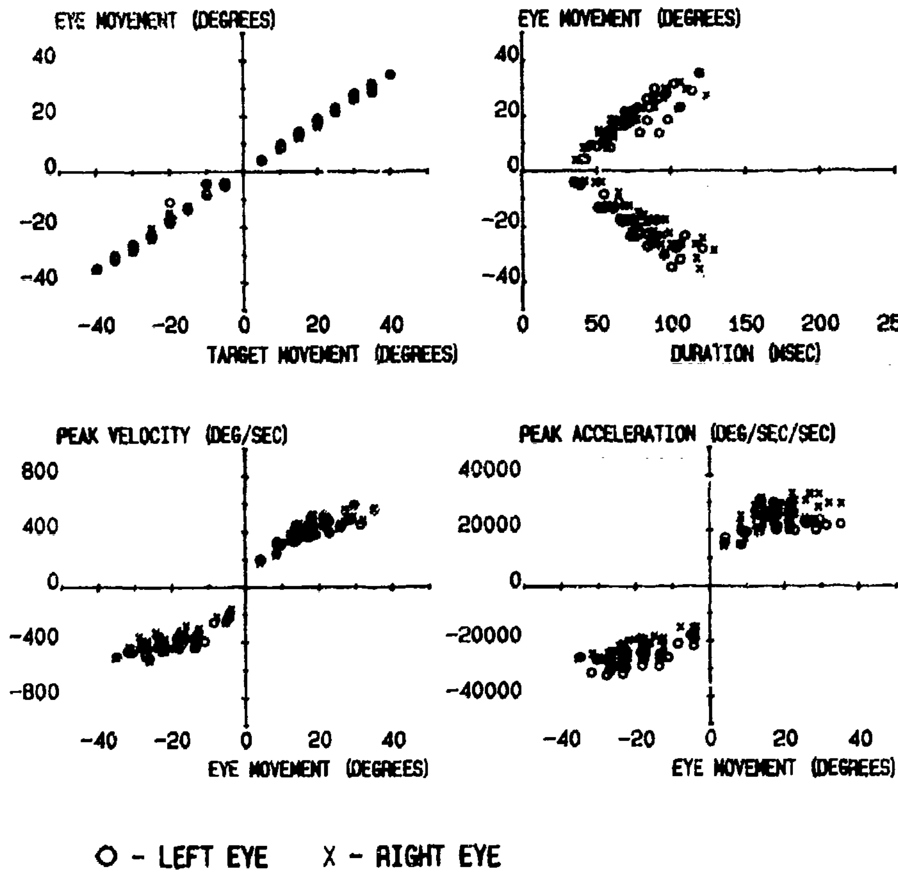

Figure 4. Binocular data from a normal subject in response to nonpredictable, discrete target movements.

DISCUSSION

It is apparent that there are methods available to adequately describe both visual and vestibular control of oculomotor function in normal aircrew members. Although scientists in various countries of the world may be using different experimental designs, their goals are the same - to more rigorously describe and quantify the input/output relationships.

Since it is not known if there is a high correlation between oculomotor function and visual perception, there is still a need for continued basic research, especially in the area of dynamic visual acuity. For example, one individual may be able to track a target at a higher velocity than another yet have the same threshold for identifying moving targets. Data from pursuit tracking studies show clearly that the use of purely binocular tracking tests does not reveal asymmetries and differences that exist with monocular inputs. Although all military pilots are presumed to have normal binocular visual function, targets and visual information often first appear in the periphery or visual field of one eye. Some pilots can quickly acquire aircraft while others, even with directions, have difficulty in finding the target. Although this situation is confounded by searching techniques and probabilities, the question still remains as to whether oculomotor dynamics play an important role in this ability.

In the case of vestibular-oculomotor function, methods are available to obtain quantitative and reliable information related to horizontal canal function. Since it is not known what the immediate or long-term effects of sudden onset high g exposure may be on the labyrinth, it is important to have at least one medical evaluation standard related to vestibular function. Since the phase measures of the VOR are highly repeatable within subjects but normally distributed between subjects, the best situation would be to have a standard set of test results for each individual. Furthermore, although high performance pilots may be selected for excellent health, eventually some percentage of them will develop pathology related to the vestibular apparatus. When that occurs, results from a rotational test performed prior to any impairment would be extremely valuable.

The use of data from any of these tests to predict performance is problematic since there is presently no standardization of techniques between civilian or military laboratories. In addition, since these tests require sophisticated data acquisition and analysis systems, the evaluation of aircrew members would have to be centralized by the various services and countries.

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VISUAL CAPABILITIES RELATED TO FIGHTER AIRCREW PERFORMANCE IN THE F-14 AND ADVERSARY AIRCRAFT

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SUMMARY

Standards for aviation personnel should be based on capacities for performing critical tasks. The purpose of this study was to determine whether scores on task-relevant visual tests could be used to predict air-to-air target detection performance of pilots involved in air combat maneuver (ACM) training.

NAMRL has developed a series of automated vision tests in a mobile field laboratory located at a Tactical Air Combat Training System (TACTS) range. A computerized telemetry network provides extensive real-time data on observer and target aircraft flight dynamics, and environmental parameters. A pilot's performance on each ACM engagement was measured by the slant range at the instant he sighted a target aircraft. (Slant range is the distance separating observer and target aircraft, inclusive of altitude separation.)

Preliminary analyses show that about 30% of the variance in slant range is accounted for by flight dynamics, environmental parameters, and vision data.

INTRODUCTION

Traditional selection and retention standards for Navy aircrew members are based upon clinical consideration of good health, and functioning of independent organ systems. These standards have been derived from established rigorous physiological criteria that have been used for clinical diagnostic purposes by highly specialized health care practitioners. The resulting aviation medical standards are extremely restrictive without necessarily demonstrating that they optimize the individual's performance on assigned operational tasks.

This research project attempts to expand the scope and depth of measures of visual capability, beyond those normally assessed in clinical settings, to include functions that may be correlated with performance of specific aviation tasks. The Vision Sciences Division at NAMRL is currently assessing visual capabilities of pilots and relating vision to the pilot's target detection performance during simulated air combat.

Although modern avionics and weapons systems enable target detection, target identification, and missile launch at distances far beyond normal visual capability, the current rules of engagement in air combat require that the target be visually identified before weapons are launched. Further, avionics can fail and be "jammed", as experienced by our aircrews in Vietnam, thus rendering vision the sole means of target detection. In Vietnam, a significant number of kills were attributed to the ability to visually detect and follow enemy aircraft.

It is readily apparent that vision continues to play a key role in air combat, and that it is important to quantify visual capability in a manner that will enable clinicians to relate clinical measures to flight performance parameters. In an attempt to satisfy this goal, 91 Navy pilots involved in ACM training were studied. The visual capabilities of these pilots were extensively evaluated, and compared to their air-to-air target detection performance. The results of this study are reported herein.

METHODS

Subjects.

Ninety-one male pilots (age, 25 to 41 years) were studied at the Tactical Air Combat Training System (TACTS) range, at NAS Oceana, VA. Two groups of pilots were distinguished. Group A consisted of 18 members of the adversary squadron station at NAS Oceana. They had accumulated an average of 1888 flying hours, with 34% of these hours in ACM. Group A pilots flew F-5 and A-4 aircraft on most ACM missions; these aircraft were not radar equipped, so these pilots depended exclusively on vision for target detection. Group B consisted of 73 pilots from seven operational squadrons participating in the Fleet Fighter Aircrew Readiness Program (FFARP). They had an average of 1749 flying hours, only 17% of which were ACM. Group B pilots flew F-14 aircraft on all ACM missions, and used both radar and vision to detect targets.

Vision Data. Six vision tests, selected on the basis of test reliability (4) and relevance to the target detection task, were administered to all 91 pilots. The six tests (listed below) are referred to by their code names (in parentheses) hereafter.

1. Central Spot Detection, minutes of visual angle (SPOT)
2. Central Acuity, high contrast, minutes of visual angle (ACHI)
3. Central Acuity, low contrast, minutes of visual angle (ACLO)
4. Central Acuity, low contrast, with glare, minutes of visual angle (GLAR)
5. Accommodative Flexibility, far to near, seconds (FLEX)
6. Lateral Movement Detection, left and right, minutes of visual angle per second (MOVE)

The test design and data collection procedures were outlined in previous reports (1-3). A mean stimulus threshold value (T) was obtained for each vision test, based on 10 threshold value determinations. For the first five tests listed, the mean threshold-stressed response time (SRT) associated with the 10 threshold determinations, was also obtained.

Target Detection Performance Data. The TACTS range incorporates a computerized telemetry system which provides real-time flight and engineering data about observer and target aircraft, on each ACM engagement. The "slant range" at the instant of the "TALLY HO" call was used as the measure of a pilot's air-to-air target detection performance. "TALLY HO" is the term used by pilots to indicate initial target detection. Slant range is the actual distance (in kilometers) separating the observer and target aircraft, inclusive of altitude separation.

Over a one year period, data were obtained for 759 ACM sorties (engagements) on the TACTS range involving these 91 pilots as observers (mean = 8.34 sorties/pilot; range, 1 to 30). The following flight dynamics and environmental variables were obtained for each sortie at the instant of "TALLY HO":

1. Visibility (kilometers), cloud coverage (clear, scattered, broken, or overcast), (cosine of) angle of the sun in the observer's visual field (range from directly in front = +1, to directly behind = -1).
2. Number of observer and target aircraft involved.
3. Slant range (kilometers), bearing, and angle off-the-tail of the target from the observer aircraft.
4. Target angle (degrees) from observer aircraft (angle between observer aircraft's direction and actual line-of-sight to target).
5. Observer and target aircraft Mach, indicated airspeed (knots), heading, altitude (meters), angle of attack, G-force, dive/climb angle, rate of climb (meters per minute/100), pitch angle, roll angle, crab angle, sideslip angle.
6. Variables computed from the above variables: altitude separation, angle of target aircraft above or below horizon, projected area (square meters) of target aircraft (includes aircraft type (size), attitude, and viewing aspect of observer), target velocity component (the component of a target aircraft's ground velocity vector perpendicular to the observer's viewing aspect, i.e., a measure of how much target movement occurred in the observer's visual field), and closing velocity (knots).

RESULTS

The average slant range at "TALLY HO" for the 759 ACM sorties was 10.96 kilometers (s.d. = 6.1; range, 0.7 to 51.7). The same mean range (10.96 km = 5.92 nautical miles) was reported for 87 ACM engagements involving F-14 and F-4 observer aircraft at the Yuma TACTS range (4). A mean range of 5.72 km was reported for 100 ACM engagements involving F-4 observer aircraft at the Yuma TACTS range (5). Some of the longer slant range values in the present data are known to have resulted from sighting of contrails or smoke, rather than the actual aircraft body. Group A pilots had an average slant range value of 12.65 km (std. dev. = 7.4; n = 347 sorties), while Group B pilots had an average slant range 9.39 km std. dev. = 4.3; n = 412 sorties). Given an average target projected area of 23.3 m^2, the average spot detection threshold (SPOT-T = .46 minutes of visual angle) would correspond to a slant range of 40.6 km; the average low contrast acuity threshold (ACLO-T = .80 mva) would correspond to a slant range of 23.3 km.

Comparison of the angular subtense of the targets (i.e., a circle having the computed projected area at the slant range distance) reveals that this difference is primarily due to the fact that Group A pilots were sighting F-14's and Group B pilots were sighting much smaller aircraft (F-5's and A-4's). Group A pilots saw targets at a mean angular subtense of 2.46 minutes of visual arc, and Group B pilots saw targets at 2.17 minutes of visual arc. Using these angular subtense values to correct for the different aircraft targets sighted by the two pilot groups, the computations can be reversed to ask what the expected slant ranges would be for the same sized target, for the two pilot groups. For a target having the average projected area ($23.3\ m^2$), Group A pilots would have an average expected slant range of 7.59 km, and Group B pilots would have an average expected slant range of 8.61 km. The ability of Group B pilots to visually detect a standard target 1.0 km farther away than Group A pilots is almost certainly due to Group B having an operational radar. The radar-associated advantage would probably be greater if both pilot groups were equally experienced in ACM.

Cloud coverage (a discrete variable) influenced slant range (Figure 1). The average slant range value was over 1.8 km greater on overcast days, than on clear days. Pearson correlation coefficients were computed between each continuous TACTS and vision variable, and slant range, for all 759 sorties, and variables significantly correlated ($P \leq .05$) with slant range were identified. Because certain TACTS variables are related (e.g., aircraft Mach, indicated airspeed, angle of attack), the significant correlations between some variables and slant range result from these inter-relationships. The primary TACTS variables significantly correlated with slant range are summarized in Table 1. The relationship between slant range and observer aircraft G-force is illustrated in Figure 2. The correlations between vision variables and slant range are given in Table 2.

Stepwise multiple regression analyses were conducted in order to evaluate the value of TACTS and vision variables in predicting air-to-air target detection performance, as measured by slant range. Dummy variables were used to represent the four categories of cloud cover (clear, scattered, broken, overcast), and the two groups of pilots (A, B). Regardless of whether all variables, or just vision or TACTS variables, were available for entry into multiple regression models, pilot group was the first variable to enter (See Table 3). This result reflects the significantly longer slant ranges for Group A pilots, who were sighting F-14 aircraft. Of all the multiple regression models generated, the best predictive power (R-squared = .296) was obtained when both vision and TACTS variables were available, and when Group A pilots were considered by themselves.

For all pilot groups, TACTS variables clearly accounted for more of the variance in slant range, than did vision variables. Target projected area, sun position, visibility and cloud coverage appeared to have more influence on slant range for Group A pilots than Group B pilots. Target angle, closing velocity, and observer sideslip angle appeared to have more influence on slant range for Group B, than Group A pilots. Observer G-force appeared to influence both pilot groups about equally.

For all pilot groups, threshold-stressed response time for the low contrast acuity vision test tended to have the greatest influence on slant range of any vision variable. Other vision tests having a significant influence ($P \leq .05$) on slant range in some models included lateral movement (to the right), spot detection, high contrast acuity, and accommodative flexibility. In general, threshold-stressed response times appeared to have at least as much value as thresholds for predicting slant range.

The multiple regression model which best predicts slant range from TACTS and vision variables, for both pilot groups (R-squared = .27), is given below:

> Slant Range = 29.35 -4.04 (Group) -.120 (target angle) -.013 (closing velocity) -1.467 (observer G-force) -.06 (projected area) +1.178 (ACLO-SPT) -.976 (cosine of sun position) -.024 (target aircraft rate of climb)
>
> where, group equals 0 if A, 1 if B

The multiple regression model which best predicts slant range from TACTS variables only, for both pilot groups (R-squared = .26), is given below:

> Slant Range = 31.58 -4.35 (Group) -.122 (target angle) -.013 (closing velocity) -1.461 (observer G-force) +1.61 (cloud cover) -.06 (projected area) -.989 (cosine of sun position) -.024 (target aircraft rate of climb)
>
> where, group equals 0 if A, 1 if B; cloud cover equals 0 if clear, scattered, or broken, 1 if overcast

DISCUSSION

The air-to-air visual target detection performance of U. S. Navy pilots training in ACM was clearly influenced by environmental, flight dynamics, and vision variables. The significantly longer slant range values associated with overcast sky conditions (Figure 1) are probably due to improved target contrast against the background. Sun positions in the observer pilot's field of vision resulted in shorter slant range values, than did sun positions behind the pilot. Because ACM training lasts throughout the day, and because observer aircraft headings are not consistent for different "TALLY HO" calls, the average sun position for all ACM sorties was directly overhead. However, of the 30 "TALLY HO's" called by pilots at slant ranges exceeding 24 km, 29 occurred when the sun was behind the pilot. The sun's position would influence target detection performance through its effect on observer canopy glare. Also, because target aircraft in ACM training are normally located in front of observer aircraft, the sun's position would affect target reflectance or glint.

Of the target aircraft variables measured, indicated airspeed had the strongest correlation with slant range, for all pilot groups. Because the correlations were greater between target indicated airspeed and slant range, than between closing velocity and slant range, the cause of this relationship ought to involve the target aircraft directly. Slower airspeeds should result in a greater concentration of exhaust smoke and hence should increase target visibility. The small (yet significant) positive correlation between slant range and the vector component of the target aircraft's ground velocity (perpendicular to the observer aircraft's viewing aspect) probably reflects increased detectability associated with increased movement of the target in the observer's visual field. The positive correlation between target projected area and slant range presumably results from a larger target being visible at a greater distance. The fact that this correlation is not higher than .079 may mean that observer pilots are detecting glint, smoke, or contrails, rather than the actual aircraft body.

The number of target aircraft (range from 1 to 6) available for detection was significantly correlated with slant range for Group A pilots only. Because they depended exclusively on vision, more available targets would increase the probability of target detection. Group B pilots typically "locked on" to a particular target aircraft with radar prior to visual detection, and were primarily concerned with calling "TALLY HO" for only that particular target.

The relationship of target aircraft sideslip angle and slant range is difficult to interpret for different groups of pilots. One confounding factor is that the average sideslip angle of Group B aircraft was over four times greater than the average sideslip angle of Group A aircraft (4.89 vs 1.12 degrees).

Four of the observer aircraft variables were significantly correlated with slant range for all pilot groups.

(1) The negative correlation with target angle means that targets directly in front of the aircraft can be seen at greater distances. In these fighter aircraft, the windscreen glass directly in front of the pilot is a planar surface; canopy reinforcing bars are positioned at each side of this flat plate, and the adjacent windscreens are curved. Thus, poorer slant range values associated with large target angles (i.e., off axis targets) could be caused by distortion, partial blockage of the visual field, or both.

(2) The correlation between observer aircraft indicated airspeed and slant range is greater than the correlation between closing velocity and slant range. This result suggests that the cause of the observer indicated airspeed vs. slant range relationship directly involves the observer aircraft. The reason for this relationship is unclear.

(3) The negative relationship between observer G-force and slant range (Figure 2) probably results from reduced visual function (e.g., loss of peripheral vision) associated with physiological stresses (6).

(4) The negative relationship between observer aircraft sideslip angle and slant range probably reflects the fact that high sideslip angles are associated with an aircraft turning. All objects in the visual field are moving in this situation.

Of the two aircraft relationship variables, closing velocity had the strongest relationship with slant range. This could simply reflect the fact that slower closing velocities allow more time to detect targets at greater distances. Alternately, this relationship could be an indirect one, owing to the direct relationships between slant range and both target and observer aircraft indicated airspeeds (see above). Altitude separation was negatively correlated with slant range for Group A pilots, but not for Group B pilots. The Group A results could be due to targets being more visible when they are in line with the horizon, or could reflect a more distorted or blocked field of view at angles above or below the observer aircraft's axis.

The several positive correlations between threshold-stressed response times and slant range indicate that longer (= slower) response times are associated with longer slant range values. The response time measures for these vision tests tended to be negatively correlated with their companion threshold measures. Possible reasons for these inter-relationships are discussed elsewhere (7). The fact that ACLO-SRT had the strongest correlation with slant range may reflect the fact that a target aircraft's contrast with its background is deliberately minimized by its color and reflectance. GLAR-T and MOVR-T were significantly correlated with slant range for Group A pilots, but not for Group B pilots, whose radar information told them exactly where to look.

Multiple regression analyses support the importance of contrast in visual detection of an aircraft target. ACLO-SRT entered the model (for both pilot groups) when both TACTS and vision variables were available; however, when only TACTS variables were available, ACLO-SRT was replaced by overcast cloud cover, a condition almost certainly associated with greater target contrast. Most of the differences between models for Group A and B pilots can be explained by their differing degrees of dependency on vision for initial target detection.

Several scenarios can be described to summarize the relationship of these TACTS data to slant range. With an operational air-to-air radar as a supplementary aid, a observer pilot can expect to detect targets visually at a longer distance if 1) he flies directly toward the target at a slow airspeed, and if 2) he avoids sharp turns or other actions that cause apparent movements of objects in the visual field ("swim"), and that produce abnormal G-forces. An observer pilot lacking an operational radar system (i.e., none in aircraft, or equipment failure) should do both of the above, plus insure that the sun is behind him and (if possible) attempt to fly at the same altitude as the target aircraft. A pilot who wishes to get as close as possible to an adversary aircraft possessing operational radar, before being detected, should fly fast and at a greatly different altitude than the adversary; for an adversary lacking operational radar, such a pilot should also fly with the sun at his back.

The multiple regression analyses indicate that slant range is more dependent upon TACTS variables than vision variables. This might be expected, given the fact that Navy pilots are a highly select group; these 91 pilots had an average high contrast acuity threshold (ACHI-T) of 0.39 minutes of visual angle, which is better than 20/10 Snellen. The greatest R-squared value (.296) means that 30% of the variance in slant range could be accounted for by all the variables used. Air-to-air visual target detection is a very complex behavior, and unmeasurable factors probably influence performance. Future research will test and refine the predictive models for slant range described here, at the TACTS range at NAS Oceana. The goal of this program is to improve air combat performance by suggesting more effective methods for selection, retention, and training of aircrew members.

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TABLE 1. CORRELATION COEFFICIENTS BETWEEN SELECTED ENVIRONMENTAL AND FLIGHT DYNAMICS VARIABLES AND SLANT RANGE, FOR DIFFERENT PILOT GROUPS

	PILOT GROUPS		
VARIABLES	A & B (n = 759 sorties)	A (n = 347 sorties)	B (n = 412 sorties)
ENVIRONMENTAL			
- sun position	-.199**	-.130*	.015
TARGET AIRCRAFT			
- indicated airspeed	-.178**	-.228**	-.089
- vector component of ground velocity	.082*	.079	.083
- sideslip angle	.171**	-.071	-.051
- projected area	.079*	-.095	.012
- number of target aircraft	.049	.147*	-.027
OBSERVER AIRCRAFT			
- target angle	-.133**	-.185**	-.2[illegible]**
- indicated airspeed	-.270**	-.199**	-.226**
- G-force	-.190**	-.223**	-.202**
- sideslip angle	-.185**	-.126*	-.242**
AIRCRAFT RELATIONSHIPS			
- altitude separation	-.067	-.132*	.030
- closing velocity	-.130**	-.195**	.056

* = P ≤ .05
** = P ≤ .0005

TABLE 2. CORRELATION COEFFICIENTS BETWEEN VISION VARIABLES AND SLANT RANGE, FOR DIFFERENT PILOT GROUPS

	PILOT GROUPS		
VARIABLES	A & B (n = 759 sorties)	A (n = 347 sorties)	B (n = 412 sorties)
SPOT-T	.008	-.043	-.088
ACHI-T	-.098*	-.032	-.128*
ACLO-T	.012	-.105	-.032
GLAR-T	.020	-.128*	.020
FLEX-T	-.008	-.078	-.064
MOVL-T	.059	-.096	.028
MOVR-T	.072*	-.138*	-.000
SPOT-SRT	.096*	-.0[illegible]	-.088
ACHI-SRT	.100*	.008	.129**
ACLO-SRT	.190***	.135*	.143**
GLAR-SRT	.145***	.042	-.007
FLEX-SRT	.056	.069	.056

* = P < .05
** = P ≤ .005
*** = P ≤ .0005

TABLE 3. RESULTS OF STEPWISE MULTIPLE REGRESSIONS FOR THE DEPENDENT VARIABLE SLANT RANGE, USING DIFFERENT GROUPS OF PILOTS AND INDEPENDENT VARIABLES. VARIABLES ARE LISTED IN THEIR ORDER OF ENTRY INTO MODELS. ($P \leq .05$ FOR ENTRY AND RETENTION IN MODELS).

GROUPS OF VARIABLES	PILOT GROUPS		
	A & B	A	B
VISION AND TACTS VARIABLES	$R^2 = .270$ 1. Group 2. Target angle 3. Closing velocity 4. Observer G-force 5. Projected area 6. ACLO-SRT 7. Sun position 8. Target rate of climb	$R^2 = .296$ 1. Target Mach 2. Cloud cover 3. Observer G-force 4. Visibility 5. ACLO-SRT 6. SPOT-SRT 7. Target angle 8. Closing velocity 9. Projected area 10. Sun position 11. FLEX-T	$R^2 = .211$ 1. Target angle 2. Closing velocity 3. Observer G-force 4. ACHI-SRT 5. Observer sideslip angle 6. Target altitude
VISION VARIABLES ONLY	$R^2 = .099$ 1. Group 2. ACLO-SRT 3. MOVR-T	$R^2 = .034$ 1. MOVR-T 2. ACLO-SRT	$R^2 = .044$ 1. ACLO-SRT 2. ACHI-T 3. ACLO-T
TACTS VARIABLES ONLY	$R^2 = .260$ 1. Group 2. Target angle 3. Closing velocity 4. Observer G-force 5. Cloud cover 6. Projected area 7. Sun position 8. Target rate of climb	$R^2 = .263$ 1. Cloud cover 2. Observer G-force 3. Target angle 4. Closing velocity 5. Projected area 6. Sun position	$R^2 = .205$ 1. Target angle 2. Closing velocity 3. Observer G-force 4. Observer sideslip angle 5. Cloud cover 6. Target angle of attack

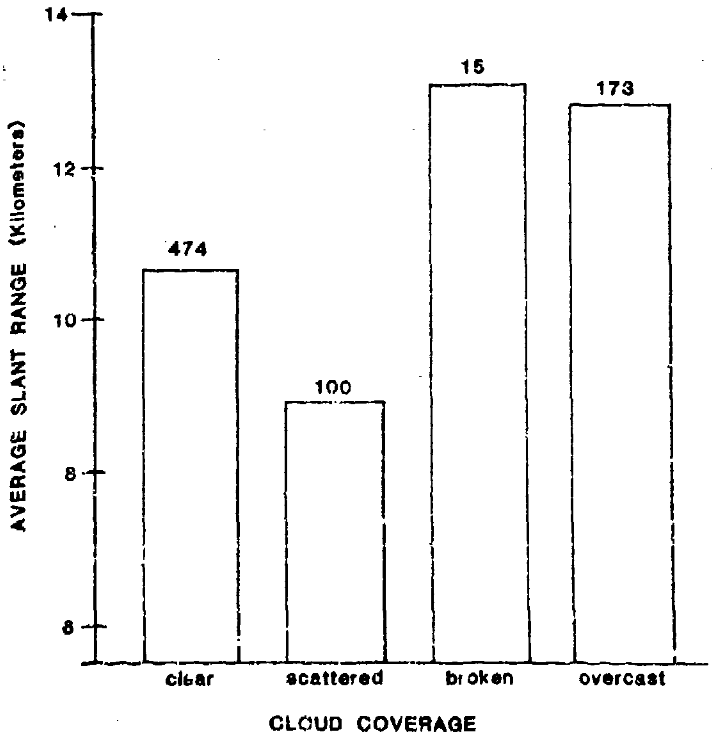

Figure 1. Average slant ranges for four categories of cloud cover conditions during 759 ACM engagements. Numbers over each histogram bar indicate number of engagements for that condition.

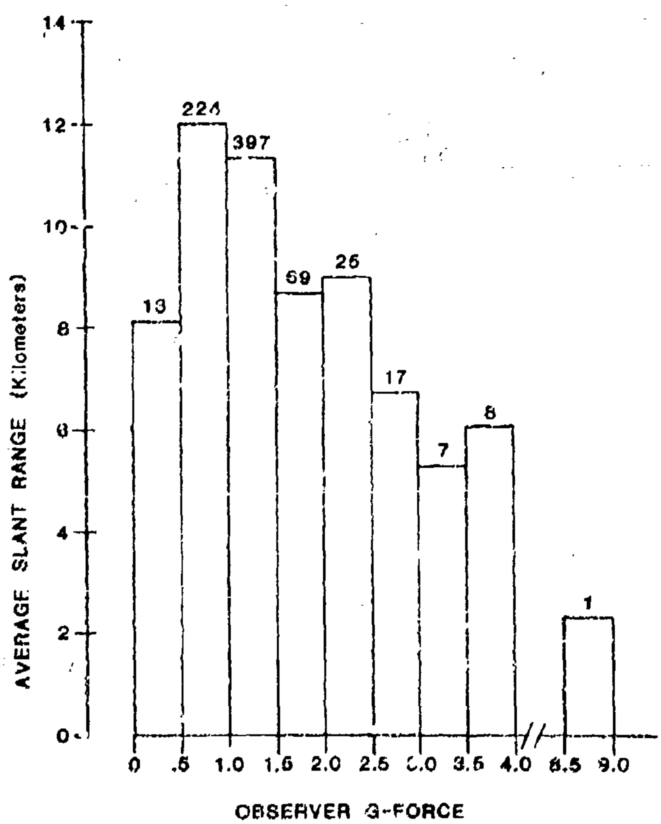

Figure 2. Average slant ranges for increments of observer aircraft G-force, based on 759 ACM engagements. Numbers over each histogram bar indicate number of engagements for that G-force increment.

VISION TEST BATTERY THRESHOLD AND RESPONSE TIME AS PREDICTORS OF AIR-TO-AIR VISUAL TARGET ACQUISITION IN F-14 AND ADVERSARY AIRCRAFT

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SUMMARY

The NAMRL Vision Test Battery provides assessment of various visual functions, including spot detection, acuity at high and low contrast, glare sensitivity, and accommodative flexibility. Within these tests are measures of threshold, threshold-stressed response time (for near-threshold stimuli), and unconfounded response time (for supra-threshold stimuli).

The contribution of response time variables to predicting flight performance was evaluated for 73 fighter pilots. Vision test data were compared to performance in air combat maneuver training. The distance (slant range) between the observer and target aircraft at time of initial visual detection was used as the performance variable.

Availability of response time variables enhanced the ability to predict the air-to-air visual target detection performance of these pilots. Four vision variables accounted for about 32% of the variance in performance of those pilots who detected target aircraft at slant ranges greater than the group average. Prediction of performance is improved by incorporating other vision data and additional refinement of the performance measure.

INTRODUCTION

For several years a major program has been in progress at the Naval Aerospace Medical Research Laboratory to develop and validate a battery of vision tests for assessing those visual functions which influence mission effectiveness in naval aviation. An automated, optical-mechanical testing system has been developed and successfully used to make vision measurements such as acuity at high and low contrast, spot detection, glare sensitivity, and accommodative flexibility. Recorded in each of these tests is a measure of the response time. The inverse relationship between response time and ability to detect the stimulus is well established (1). Response time is an established and useful measure of mental processing and coordinated activity.

In the past, air-to-air visual target detection performance has been predicted primarily using visual threshold data from the NAMRL Vision Test Battery (VTB). However, Erickson (2) found that laboratory visual search time scores of 22 Navy pilots were not related to visual acuity but were significantly correlated with response time measures. Although the VTB threshold data alone account for some of the variance in pilot performance, the use of response time data instead of, or in addition to, threshold data could improve predictive power. In this study, the contribution of response time data in predicting air-to-air target detection performance of pilots is examined.

METHODS

SUBJECTS

Seventy-three experienced male Navy pilots attached to Fighter Wing One, NAS, Oceana, VA, participated in this project. The subjects ranged in age from 25 to 41 years (mean = 30.3), and ranged in flying experience (total flying hours) from 400 to 4500 hours (mean = 1750). All subjects demonstrated excellent visual acuity (at least 20/20 Snellen acuity) and possessed the superior practical visual skills required for flying advanced aircraft. Therefore, they were a highly select group, both in terms of vision test scores and successful job performance.

APPARATUS

The Vision Test Battery (VTB) equipment and digital control system have been described elsewhere in greater detail (3,4). The VTB consists of an optical projection system with random-access slide projectors, timing shutters, and a response joystick, all integrated through a digital controller linked to a Hewlett-Packard 9825 computer via various interfaces and multi-programmers. The test targets were a series of precision Landolt "C" rings and single spots on high-resolution photographic emulsion-on-glass slides (5). The "C" patterns were oriented with the gap up, down, right, or left at random. Targets were

presented for 3 seconds duration in all tests, except for the accommodative flexibility test where exposure time was the experimental variable. The background screen illumination level was 343 cd/m2 (100 foot Lamberts), and the high intensity glare condition was approximately 3000 cd/m2. The high and low contrast targets were 100% and 10% target-to-background ratio, respectively. The accommodative flexibility test required the subject to read targets at a far distance of 5.5 m, then at a near distance of 0.47 m. The other automated tests in this study involved a far observing distance of 5.5 m.

PROCEDURE

Five vision tests which included a response time measure were selected from the extensive Vision Test Battery series for this analysis. The five tests are summarized in Table 1. The test code names are used in all subsequent tables. The various types of tests involve different task complexities. The spot detection test (SPOT) is the simplest task (two response choices, one judgment to reply), the acuity tests (ACHI, ACLO, GLAR) are more complex (four choices, one judgment) and the accommodative flexibility test (FLEX) involves the most complex task (four choices, two judgments).

After the presentation of a fixation pattern, the target images of Landolt "C" rings or spots were presented. The subject was required to respond manually with a four-choice lever indicating either gap orientation or yes-no detection of the spot. The subject's response time was measured from the onset of the stimulus target to his response. For each test, 10 practice trials were given, followed by 40 or more test trials.

A modified staircase (von Bekesy) psychophysical testing procedures with forced-choice response was employed. The difficulty of successive test trials was increased until the subject gave an incorrect response; then difficulty was decreased until a correct response was given (which determined the first threshold); difficulty was then increased again until the next error, and so forth. In the acuity tests, the Landolt "C" was reduced in size on each trial, as long as the gap orientation response was correct. In the spot detection test, the subject reported "yes" or "no" for detection at each trial while target sizes were reduced or increased appropriately. For the accommodative flexibility test, two Landolt "C" targets (gap size = two minutes of arc) displayed simultaneously, one at far and one at near observation distance. Target presentation time was reduced for each trial, as long as the subject gave correct responses for both targets. Since subjects had to make two responses, and since the threshold was determined by the second response, response times were longer in this test than in other tests. For all five tests, one threshold value was the average of the target size (or time) reported incorrectly and the size (or time) reported correctly. The mean of ten such threshold values was taken as the test threshold (T) score.

RESPONSE TIME ANALYSIS

In typical response time studies, analysis is performed on error-free or correct response data to an above-threshold stimulus of constant size, intensity, or duration. Data using the same size target will usually remain relatively stable across trials, or decrease slightly with practice. An incorrect judgment can be confounded by many factors, not the least of which is the "guess" response required in the forced-choice method when the target is apparently not resolved. In effect, the response time for such a "guess" is the time it takes to not recognize a target. Since one cannot assess whether an error was due to perceptual, cognitive, or motor processes, the factors contributing to response time are difficult to identify.

Unconfounded Response Time

At the beginning of each vision test, ten practice trials were given with target stimuli that were easy to discriminate. Target sizes were not repeated. Individual responses in these early trials were usually correct, so the associated response times were probably not confounded greatly by changes in target size at this suprathreshold level. Familiarity with the test procedure may have been a confounding variable (i.e., response time may have been slow for subjects who had not yet mastered the task). To obtain unconfounded response time data, three error-free practice trials were selected for each test. These trials involved target sizes which every subject received after some practice, and which were still well above the eventual threshold level. Since response time data analysis normally requires many more than three trials per condition to obtain accurate means and indices of variability, this procedure can only be regarded as a rough estimate of unconfounded response time (URT) for each test.

Threshold-Stressed Response Time

In the staircase psychophysical procedure, the target size (or presentation time) is decreased until the threshold level is reached and an error response is given. The size is then increased until a correct response is given. In this ascending sequence, the sizes of the two targets (i.e., the one with the last wrong response and the one with the first correct response) were averaged to give a threshold value. Therefore, in the staircase method, error trials are a necessary aspect of the threshold determination process.

Measures of response time near threshold, obtained using this procedure, are confounded both by changing target sizes and by the presence of error trials. As the visual threshold level is approached, response time usually increases. Response times associated with the correct-response trials involved in computing a subject's threshold values should provide a more reliable response time measure for comparison of different subjects. For each test, we identified the (incorrect-correct) trial pairs used to establish the subject's threshold score. The response time was noted for the trial in each pair which had the larger target and correct response. This was the time it took for the subject to respond to a target which he could "just see" correctly. The mean of these 10 response time values was calculated and called the <u>threshold-stressed response time</u> (SRT).

Relevant questions about the response time data addressed in this report include: Do URT and SRT vary with test complexity? Are URT and SRT values consistent across tests? Are URT and SRT values correlated with one another? How is response time related to threshold for each test? Do response time variables enhance the ability to predict air-to-air visual target detection performance?

PERFORMANCE MEASURE

The air-to-air visual target detection performance of the 73 pilots was determined from data obtained at the Tactical Air Combat Training System (TACTS) range at NAS Oceana, VA. The pilots were from seven operational squadrons undergoing air combat maneuver (ACM) training at the TACTS range. During ACM, a pilot called "TALLY HO" over his radio at the instant he sighted an adversary (target) aircraft. Telemetry data indicated the "slant range" at this instant. Slant range is the distance (in kilometers) separating the observer and target aircraft, inclusive of any altitude separation. In this study, a pilot's average slant range score, based on up to 30 "TALLY HO" calls during ACM, was used as the measure of his air-to-air visual target detection performance.

RESULTS

The 73 pilots sighted target aircraft at an average slant range distance of 8.78 km (std. dev. = 2.45; range = 3.5 to 14.1). Two pilot subgroups were distinguished, based on the whole group's average slant range score of 8.78 km. The "above-average" subgroup of pilots saw target aircraft at an average distance greater than 8.78 km, and the "below-average" subgroup of pilots saw target aircraft at an average distance less than 8.78 km.

Threshold means and standard deviations for visual acuity tests increased with decreased contrast difference and with the addition of glare (see Table 2). The mean value of .402 minutes visual angle (mva) (better than 20/10 Snellen) for the high contrast acuity test demonstrates the excellent vision of these subjects. In all five vision tests, the mean unconfounded response time (URT) was less than the mean threshold-stressed response time (SRT) across all pilots, and for both pilot subgroups. This difference is basically attributable to differences in target size. The URT's increased (became slower) as task complexity increased (see Tables 1 and 2). The shortest mean URT was for the spot detection test (two choices, one judgment), and the longest mean URT was for the accommodative flexibility test (four choices, two judgments). A similar trend held for the SRT's. For all five tests, the mean threshold (T) for the "above-average" subgroup is slightly better (smaller) than for the "below-average" subgroup. Individual t-tests performed on all threshold (T), unconfounded response time (URT), and threshold-stressed response time (SRT) variables indicated no significant differences ($P > .05$) between the "above-average" and "below-average" pilots.

Analysis of response time inter-correlations permits determination of the consistency of response time variables across subjects and across tests (Tables 3 and 4). Of 25 possible inter-correlations between unconfounded (URT) and threshold-stressed (SRT) response times, only five (20%) were significant ($P < .05$); four of the five correlations were for URT and SRT values from the same vision test. Thus, 19 of the 20 cross-test URT-SRT correlations were not significant, indicating poor cross-test consistency between these variables. While unconfounded response time (URT) showed better cross-test consistency (60% of the URT-URT inter-correlations were significant, at $P < .05$), threshold-stressed response time (SRT) showed the greatest consistency among tests (80% of the SRT-SRT inter-correlations were significant, all at $P < .005$). The two non-significant SRT-SRT inter-correlations both involved the accommodative flexibility test, which presented subjects with the most complex task. This analysis suggests that threshold-stressed response time (SRT) has the greatest cross-test consistency, and hence that SRT might be the more useful response time measure for predicting pilot performance.

For all 73 pilots, the threshold and threshold-stressed response time for the high contrast acuity test (ACHI-T, ACHI-SRT) were the only variables significantly correlated ($P < .05$) with air-to-air visual target detection performance, as measured by slant range (Tables 4 and 5). ACHI-T was negatively correlated ($r = -.250$) with slant range (i.e., lower threshold, longer slant range distance), and ACHI-SRT was positively correlated ($r = .226$) with slant range (i.e., longer response time, longer slant range distance). Interestingly, all five vision test thresholds (T's) were negatively correlated with their

companion threshold-stressed response times (SRT's), with four of the five correlations being significant at ($P < .05$) or better. (The FLEX-T versus FLEX-SRT correlation was not significant.) Thus, pilots with better (= lower) visual threshold scores had slower (= longer) response times.

Four of the five vision test thresholds (T's) and ACHI-SRT, were significantly correlated ($P < .05$) with pilot age, and all but one of these variables were correlated significantly with flying experience (Table 5). Older pilots had higher thresholds on all five vision tests. However, neither age nor flying experience were significantly correlated with air-to-air visual target detection performance, as measured by raw slant range data. Also, the poorest high-contrast acuity value for any pilot was .72 mva (better than 20/15 Snellen), which indicates that all pilots had excellent vision, regardless of age.

Stepwise multiple regression analysis (Table 6) revealed that response time variables improved the ability to predict air-to-air visual target detection performance, as measured by slant range. Regardless of whether all pilots or the performance-defined pilot subgroups were considered, a higher adjusted R-squared value was obtained when response time variables were made available for entry into the model, than when they were not. (The adjusted R-squared value compensates for inflation in R-squared associated with the proportion of variables entering the model, to the number of observations). The ability to predict performance of all pilots was rather low (Adj. R-squared = .12). However, about 32% of the variance (Adj. R-squared = .32) in performance of "above-average" pilots could be accounted for when response time variables were available for entry into the model. Furthermore, for "below-average" pilots, response time variables by themselves accounted for more of the variance in performance (Adj. R-squared = .20) than did threshold variables by themselves (Adj. R-squared = .06).

DISCUSSION

In all tests, threshold-stressed response time (SRT) was slower than unconfounded response time (URT) due to the difficulty of seeing the critical target characteristics near visual threshold (See Table 2). Threshold-stressed response times showed better cross-test consistency than unconfounded response times. The lower cross-test consistency of URT values could be due to greater variation in this measure resulting from its being a mean of only three response time values for each subject. Also, because different subjects had different visual threshold levels, the degree of difficulty involved in seeing the three target sizes used to obtain URT values varied among subjects. The factors responsible for the significant positive correlation between slant range and ACHI-SRT (i.e., pilots with slower response time scores see target aircraft at longer distances) are unclear. All five SRT variables were positively correlated with the subject's slant range, and negatively correlated with their companion threshold (T) variable. Thus the positive correlation between ACHI-SRT and slant range may indicate only an indirect relationship, whose existence is due to a direct negative relationship between ACHI-T and slant range (lower threshold, longer slant range). It is difficult to imagine how ACHI-SRT could have a direct positive relationship with slant range.

This analysis shows that inclusion of response time variables along with threshold variables increases the ability to predict air-to-air visual target detection performance. The predictive power for "above-average" pilots is greater than for "below-average" pilots, but it is not clear why this is so. "Above-average" pilots may be responding closer to their neurosensory limits than "below-average" pilots.

When all 73 pilots are considered, the ability to predict performance from these vision test results alone is rather low, but may be improved in several ways. First, average slant range is a crude measure of performance. Target visibility is known to be influenced by many factors, such as target angular size, angular velocity, contrast, cloud conditions, etc. A more refined performance measure incorporating additional information collected at each sighting should yield a clearer relationship between performance and vision test results. Analyses are now being completed of telemetry data on 56 target and observer aircraft parameters for 759 ACM engagements involving Navy pilots. Second, incorporation of data from other types of vision tests should provide measures of task-relevant aspects of visual skill not treated in this report. The VTB series also included tests of lateral movement detection, contrast sensitivity, dynamic visual acuity, and dark focus. More of the variance in slant range is accounted for when data from these vision tests are available for entry into a multiple regression model. Finally, introducing a more accurate measure of a pilot's unconfounded response time (URT) may improve the ability to predict performance.

It seems clear that a more systematic examination of response time as a predictor of air-to-air visual target detection performance is warranted.

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TABLE 1. SUMMARY OF VISION TEST CONDITIONS.

Test	Code Name	Target	Response Choices	Number of Judgments
Spot Detection, high contrast	"SPOT"	Spot	Yes, No	1
Acuity, high contrast	"ACHI"	Landolt "C" ring	Up, Down, Right, Left	1
Acuity, low contrast	"ACLO"	Landolt "C" ring	Up, Down, Right, Left	1
Acuity, low contrast, with glare	"GLAR"	Landolt "C" ring	Up, Down, Right, Left	1
Accommodative Flexibility, high contrast, far-to-near distance	"FLEX"	Landolt "C" ring (at far and near)	Up, Down, Right, Left	2

TABLE 2. SUMMARY STATISTICS FOR THRESHOLD AND RESPONSE TIME DATA FOR 73 NAVY PILOTS AND TWO PERFORMANCE-DEFINED SUBGROUPS

	ALL PILOTS (N = 73)		ABOVE-AVERAGE PILOTS (N = 35)		BELOW AVERAGE PILOTS (N = 38)	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
SPOT - T	.446	.077	.431	.077	.460	.076
- URT	.496	.164	.497	.163	.494	.166
- SRT	1.068	.277	1.094	.290	1.044	.266
ACHI - T	.402	.073	.388	.054	.416	.080
- URT	.884	.241	.898	.263	.871	.221
- SRT	1.400	.388	1.449	.357	1.355	.415
ACLO - T	.763	.151	.757	.133	.769	.168
- URT	.933	.315	.940	.323	.926	.311
- SRT	1.672	.533	1.734	.539	1.615	.528
GLAR - T	.982	.244	.965	.228	.997	.260
- URT	.842	.282	.835	.289	.848	.278
- SRT	1.746	.557	1.753	.453	1.740	.644
FLEX - T	.280	.094	.265	.047	.294	.121
- URT	1.191	.276	1.175	.246	1.206	.303
- SRT	1.499	.427	1.502	.371	1.496	.477

All response times (URT, SRT) and FLEX-T in seconds.
All other thresholds (SPOT-T, ACHI-T, ACLO-T, GLAR-T) in minutes of visual angle.

TABLE 3. CORRELATION MATRIX FOR RESPONSE TIME VARIABLES AND AIR-TO-AIR TARGET DETECTION PERFORMANCE (SLANT RANGE) FOR 73 NAVY PILOTS

VARIABLE	SPOT URT	SPOT SRT	ACHI URT	ACHI SRT	ACLO URT	ACLO SRT	GLAR URT	GLAR SRT	FLEX URT	FLEX SRT	SLANT RANGE
SPOT-URT	-	.279*	.241*	.223	.248*	.211	.331**	.211	.161	.087	-.028
SPOT-SRT	-	-	.132	.333**	-.013	.473**	.036	.409**	.108	.161	.129
ACHI-URT	-	-	-	.408**	.428**	.276*	.102	.087	-.011	.002	.076
ACHI-SRT	-	-	-	-	.205	.684**	-.039	.361**	-.021	.182	.226*
ACLO-URT	-	-	-	-	-	.247*	.336**	-.060	.048	-.022	.029
ACLO-SRT	-	-	-	-	-	-	.124	.463**	.109	.354**	.171
GLAR-URT	-	-	-	-	-	-	-	.101	.333**	.043	.020
GLAR-SRT	-	-	-	-	-	-	-	-	.200	.392**	.015
FLEX-URT	-	-	-	-	-	-	-	-	-	.479**	.083
FLEX-SRT	-	-	-	-	-	-	-	-	-	-	.128
SLANT RANGE	-	-	-	-	-	-	-	-	-	-	-

* = $P < .05$
** = $P < .005$

TABLE 4. SUMMARY OF RESPONSE TIME INTER-CORRELATIONS IN TABLE 3.

	TYPES OF RESPONSE TIME VARIABLES COMPARED		
	URT-URT	URT-SRT	SRT-SRT
Number of Correlations Not Significant, $P > .05$	4	20	2
Number of Correlations Significant, $P < .05$	6	5	8
Total Number of Correlations	10	25	10
Percent of Correlations Significant, $P < .05$	60%	20%	80%

TABLE 5. CORRELATION MATRIX FOR THRESHOLD AND THRESHOLD-STRESSED RESPONSE TIME VARIABLES, PERFORMANCE (SLANT RANGE), AGE, AND EXPERIENCE (TOTAL FLYING HOURS) FOR 73 NAVY PILOTS

VARIABLE	SPOT T	SPOT SRT	ACHI T	ACHI SRT	ACLO T	ACLO SRT	GLAR T	GLAR SRT	FLEX T	FLEX SRT	SLANT RANGE	AGE	EXPERIENCE
SPOT-T	-	-.229*	.423**	-.077	.506**	-.013	.509**	-.110	.140	-.031	-.177	.275*	.194
SPOT-SRT	-	-	-.022	.333**	.021	.473**	-.143	.409**	-.088	.161	.129	-.137	-.126
ACHI-T	-	-	-	-.398**	.670**	-.124	.387**	-.083	.247*	-.189	-.250*	.210	.212
ACHI-SRT	-	-	-	-	-.335**	.684**	-.233*	.361**	-.247*	.182	.226*	-.295*	-.307*
ACLO-T	-	-	-	-	-	-.241*	.706**	-.217	.117	-.195	-.016	.291*	.277*
ACLO-SRT	-	-	-	-	-	-	-.076	.463**	-.156	.354**	.171	-.144	-.189
GLAR-T	-	-	-	-	-	-	-	-.319*	.174	-.155	.043	.383**	.334**
GLAR-SRT	-	-	-	-	-	-	-	-	.021	.392**	.015	-.128	-.098
FLEX-T	-	-	-	-	-	-	-	-	-	-.032	-.074	.449**	.311*
FLEX-SRT	-	-	-	-	-	-	-	-	-	-	.128	-.025	.025
SLANT RANGE	-	-	-	-	-	-	-	-	-	-	-	.058	.037
AGE	-	-	-	-	-	-	-	-	-	-	-	-	.819**
EXPERIENCE	-	-	-	-	-	-	-	-	-	-	-	-	-

* = P <.05
** = P <.005

TABLE 6. VISION TEST VARIABLES ENTERING PREDICTIVE MODEL OF PERFORMANCE (SLANT RANGE), FOR DIFFERENT COMBINATIONS OF SUBJECTS AND VARIABLES.

SUBJECT GROUP	TYPES OF VISION VARIABLES AVAILABLE FOR ENTRY: THRESHOLDS ONLY	THRESHOLDS AND RESPONSE TIMES	RESPONSE TIMES ONLY
All Pilots (n = 73)	ACHI-T ACLO-T Adj. R^2=.08	ACHI-T ACLO-T ACLO-SRT SPOT-T Adj. R^2=.12	ACHI-SRT Adj. R^2=.04
Above-Average Pilots (n = 35)	FLEX-T GLAR-T ACHI-T Adj. R^2=.17	ACHI-SRT GLAR-T FLEX-T SPOT-T Adj. R^2=.32	ACHI-SRT GLAR-SRT Adj. R^2 =.13
Below-Average Pilots (n = 38)	FLEX-T Adj. R^2=.06	FLEX-URT SPOT-URT Adj. R^2=.20	FLEX-URT SPOT-URT Adj. R^2=.20

P <.15 for entry and retention in the model.
Variables are listed in order of entry for each model.

DISCUSSION OF SESSION IV - MEDICAL SELECTION: VISION ASPECTS

(Papers 35, 36, 37, 38 and 39)

DR ZWICK (US)

I have a question for Dr Santucci. When Ginsburg did his contrast sensitivity tests he also ran some tests correlating contrast sensitivity with performance in fighter aircraft. Have you run similar tests/correlations?

AUTHOR'S REPLY (MÉD EN CHEF SANTUCCI (FR))

No, we have not undertaken tests of the kind which Dr Ginsberg performed.

DR SALLAVANTI (US)

I'm from the Gentex Corporation, US. I have a question for Dr Brennan. You showed a slide of a hazed visor and in earlier remarks you indicated that you had seen or been aware of small cracks or fissure like deficiencies which you felt were associated with ballistic fractures in visors. Would you care to comment on that please?

AUTHOR'S REPLY (DR BRENNAN (UK))

Yes, our visors are currently uncoated because of this problem. When they are hard coated, breaks can propagate from small fractures. I'd be very interested to hear your views on what sort of coating should be used or if its possible to change the polycarbonate substrate in any way to prevent this propagation.

DR SALLAVANTI (US)

It has been known for some time that coating polycarbonate (which is not a compound but a mixture, and being polymeric can be compounded in a number of ways) affects its ultimate ballistic properties. When one coats polycarbonate with a silicone coating, an acrylic coating or a urethane coating that is either thermally, ultra violet or electron beam cured you cause alterations that exacerbate some of the stresses that are due to injection moulding. It is often along these lines that ballistic fractures occur. I would suggest that you should look at some of the newer coatings which are not silicone derivatives. These coatings are more flexible, they lend abrasion resistance to the polycarbonate, and they do not cause the degradation associated with silicone coats. The degradation in ballistic properties with hard silicone coatings can be as much as 15% or 20% which still places the coated polycarbonate well above optical resins such as CR39. However, a more flexible coating produces virtually no degradation in ballistic properties.

AUTHOR'S REPLY (DR BRENNAN (UK))

I take the point but does the more flexible coating you are suggesting provide good resistance against abrasion and can you assure one that it has no effect, for example, on the amount of inherent haze in the material? And thirdly, using another approach, can you in any way change the substrate to prevent fracturing occurring with the harder coats?

DR SALLAVANTI (US)

Well, to answer the second part first. Yes one can change the substrate within polycarbonate. There is a number of commercially available high performance resins that ensure optimal ballistic performance in the coated state. In terms of the softer coating, we have not experienced any haze problems over a 2 year period of use - the US MIL spec standards are adequately met. Our tests for abrasion tend to be quantitative in terms of judging what the haze after a test is done. Some of these tests are passed by the more flexible coatings and some are not; the more rigorous ones will not be met.

LT COL GRAY (CA)

I have a question for Dr Brennan. I was intrigued by your suggestion that we eliminate pilot candidates with any degree of myopia whatsoever and only allow people who are ametropic or slightly hypermetropic into pilot training. I wonder if you have any idea what percentage of RAF candidates that might eliminate? I know in our system in people who have already been screened at a basic recruiting centre level we would still probably find 25-30% who are slightly myopic. The corollary to that question is I wonder what evidence you would be able to put forth to justify eliminating all myopics? One of the problems we encounter now, and I'm not sure what other countries are having the same problem, is justifying our present standards in the face of our new human rights legislation. Candidates are asking more and more what evidence we have to justify any sort of standards, including our visual standards.

AUTHOR'S REPLY (DR BRENNAN (UK))

In response to your first question, I cannot give you figures on the proportion of candidates who would be excluded. I imagine these figures could be obtained but I cannot give them to you at the moment. I can tell you, however, that currently 15% of our aircrew wear spectacles - mind you a fair percentage of that 15% are presbyopes. So I'm not sure of the proportion who are myopes but it would not be that large. In answer to your second question, the reason I would wish to exclude myopes is that myopia can be, in young men, progressive. If we admit somebody with a quarter of a dioptre of myopia which produces minimal visual degradation it may well be that within 2 or 3 years time, when he has been through pilot training at vast expense, he will have to wear spectacles. As I pointed out in my paper, it is then yet one more embarrassment to the pilot. His visual task is difficult enough without asking him to wear spectacles as well. As regards human rights, I won't make any comments!

COL PRICE (US)

Just to confirm what Dr Brennan said. We did a survey where we looked at the ametropes who came into Army aviation to see what happened to them over a 10 year period. Seven percent of the physiologically ametropes developed myopia requiring correction. I think that finding is pretty consistent with other studies which have been done. Our study showed that if you cut off selection at absolutely no myopia, or insisted on a small amount of hyperopia you could reduce the proportion requiring spectacles to about 1%, or 1-2%. If on the other hand you accept people who are a quarter dioptre myopes but physiologically don't require correction, they are most likely to go on to develop myopia requiring correction.

DR LANDOLT (CA)

Dr Wolfe, to what extent are you using otolithic function tests in your protocol because this is becoming important not just for the high G effects but also because of the direct decoupling manoeuvring modes?

AUTHOR'S REPLY (DR WOLFE (US))

Yes, I agree that otolith function testing is important. We are not doing any posturegraphy. Dr Lou Naster on the West Coast has developed looking at the phase gain parameters of a person standing in both a visual environment and non visual environment. They seem to be very sensitive tests of otolith function. We have not employed these tests at USAF SAM mainly because of lack of effort. We have been generating and developing rotational tests and tracking tests. We should consider I suggest how many of these tests can you meaningfully do on a normal individual. Early in the astronaut programme the candidates underwent weeks and weeks of testing. The Aerospace Medical Panel, which has the appropriate experts, could set up a programme to look at the testing of canal and otolith function. Postureography is a valuable technique which I believe is not being used clinically in any the military hospital or laboratory. On the other hand the rotational testing and tracking testing which we have developed at the School have been implemented in about 40 medical centres around the world. Brooks Air Force Base and Wilford Hall Hospital are the only two military installations in the whole world that are evaluating their patients using these tests. Its the contrast sensitivity/Snellen Chart kind of problem. The old time otolaryngologist thinks that there is nothing better than a good caloric. As we know you can have normal calorics and abnormal rotational tests and you can have normal rotational tests and an abnormal caloric test. So ideally you should perform both of these tests but it would require 4-6 hours to evaluate one patient. I think that if you had to do one test, your point is well taken. With high performance pilots you should perform sophisticated otolith testing. My main point would be "Is there a correlation between the overall oculomotor function and performance in a combat environment situation - Is your ability to perceive the HUD and all these other things that are going on related to both your canals and the oculomotor system?" In the case of the otolith test I think you are looking more at damage and what is the sudden G doing. Twenty years ago we did a study on the centrifuge. We found that with only 3 G exposure, some of the subjects had positional nystagmus for a week following the exposure. This suggested that exposure to G may well be doing some damage. I think a critical question in the case of aircrew is, at what point is the flight environment inducing some pathology in these people who are frequently disorientated. Now how much of that is due to end-organ dysfunction? I agree with you, I think otolith tests should be looked at.

AIR CDRE ERNSTING (UK)

Has the United States Air Force introduced contrast sensitivity testing into its aircrew selection procedures?

COL GIBBONS (US)

At present it isn't a standard test. It is being evaluated by the ophthalmology branch at the School of Aerospace Medicine to determine if it should be included.

COL PRICE (US)

Has anyone introduced contrast sensitivity for, or at the time of, selection even for maintaining a data base?

LT COL GRAY (CA)

We are in the midst of evaluating contrast sensitivity in terms of a data base. We are, however, not using it for selection. We want to build up a data base of normals. We certainly intend to introduce it later. We have used it in the few examples I showed this morning for detecting individuals who otherwise would have slipped through the system - the young chap who had optic neuritis and the other chap who had been treated by orthokarotology. In these two cases it was used for selection but only because it undercovered an underlying condition.

DR FARR (US)

A question for Dr Gray following up the conversation this morning. You stopped short of identifying a criterion that might be used for contrast sensitivity standards. From your slides I inferred that the criterion might be something like the 10%/90% limits of normal standards. Is that what you had in mind and, if so, what kind of data support that criterion?

LT COL GRAY (CA)

At this point those limits are certainly not intended to be our selection criteria. They were only to indicate the range of scatter of the data we have collected so far. Before those kind of limit are introduced as a screening or selection criterion they will have to be correlated with other variables such as target detection or success in pilot training. Certainly from our human rights point of view we would not be able to introduce an arbitrary test without any sort of correlation with performance data.

DR BRENNAN (UK)

So really you are considering constrast sensitivity testing as a net to catch pathology which might otherwise have escaped detection?

LT COL GRAY (CA)

Well at this point that's how it has been useful to us. What we are really doing is building up a data base of normal aircrew candidates who are coming through the Central Medical Board. We will compare our data base with the few other population studies that have been done. With the intention, after we have performed studies correlating it with performance variables, of introducing it as a screening test. Right now the value it has been to us is as a net to catch those few candidates who had undiscovered eye pathology.

DR BRENNAN (UK)

Are you postulating that in the future that you will wish to use it to determine those aircrew who could only perform well under high contrast conditions? Would you use it to select aircrew on that basis? Is that your ultimate intention?

LT COL GRAY (CA)

Yes it is. We are certainly intending to use it that way and also to help sort out candidates who are borderline. As you know, the error in performing a cycloplegic refraction to detect somebody who is ametropic is at least a quarter of a dioptre. Suppose we have a candidate who has been examined by two different ophthalmologists who have found a quarter and one half dioptre ametropia respectively. If we have a standard of a quarter dioptre do we accept or reject him? Another way of looking at his visual function such as contrast sensitivity might give us another factor in the equation to decide whether he is acceptable or not.

DR BRENNAN (UK)

I rather doubt whether it would! I would think the fact whether he has a quarter of a dioptre or a half of a dioptre ametropia might affect the highest spatial frequencies of the constrast sensitivity test which is monitoring precisely what the Snellen does.

LT COL GRAY (CA)

Well, we have looked at the correlation between our cycloplegic refractor and the contrast sensitivities at all the spatial frequencies from 1 to 24 cycles per degree. There was no correlation between spherical equivalent and cycloplegic refractor in the pilot candidates who are all fairly normal sighted and who have only a small error because those with larger errors have already been screened out. In individuals with refractive errors between plus one dioptre and minus half a dioptre there was no correlation even at 24 cycles per degree between the contrast sensitivity and their refractive state.

DR BRENNAN (UK)

Do you peform cycloplegic refractions as a routine? Do you think this test on what is essentially an abnormal eye, as the shape of the lens is changed under cycloplegia and the pupil is dilated you are getting spherical errors from the lens periphery? You have got to do a post mydriatic test even if you do a cycloplegic reaction. Do you really think it worthwhile?

LT COL GRAY (CA)

Well, I'm not an ophthalmologist, I'm an internist. All I can say is that yet we perform cycloplegic refraction on everyone. I think almost everybody does. Our standards are minus a quarter dioptre of myopia or spherical equivalent. I think its something that you have to do but that it is a mistake to use it as the only standard. It is one part of the overall examination.

DR BRENNAN

I don't know what other countries do but we certainly don't use it!

DR ALNAES (NO)

A question to Dr Santucci. I understand the Snellen chart is in a way the same as the high frequency, high contrast part of the contrast screen. The fact that myopes do not resolve the blue colour as ametropes do - was this even in the corrected myopic eye? Is it something that persists even after spectacle correction?

AUTHOR'S REPLY (MÉD EN CHEF SANTUCCI (FR))

The attenuation in the high spatial frequencies does disappear when the myopia is corrected. Mention is made of contrast sensitivity. I consider that contrast sensitivity should be studied under dynamic conditions as well as static conditions before it is adopted as a new test. In our research programme we are collecting a bank of data which will allow us to establish the contrast sensitivity curve under dynamic conditions with the grating being shifted over to the right or to the left at different velocities. Obviously this test will complicate the examination but of course the task of the pilot is to detect targets in motion and not in static conditions. Contrast sensitivity proper is very interesting but before it is adopted as a test we should explore this technique further. Lack of sensitivity to contrast during motion of the target is also of interest.

DR BRENNAN (UK)

Are you intending then to use drifting gratings with them drifting at different speeds?

AUTHOR'S REPLY (MÉD EN CHEF SANTUCCI (FR))

Absolutely. We do intend to use these type of gratings.

COL PRICE (US)

Dr Monaco, I was wondering about the lateral movement which was correlated with, I believe, a faster response time in one group of your pilots. Would you explain just what you mean by lateral movement and how you think that particular function is helping the pilot? I believe you said lateral movement to the right as you presented it but when I read this I believe it said to the left.

AUTHOR'S REPLY (CDR MONACO (US))

Our lateral movement test involves the movement of a fixed size spot, the angular subtend of that spot at 6 metre distance is approximately equivalent to a 20/40 letter. The way we measure lateral movement is the subject's response to the movement of that spot. He has to determine whether the spot is moving to the left or to the right. So he has a choice of either direction. Thus in this test we measure the threshold sensitivity to lateral movement to the left or right of a spot target both in the left and right direction simultaneously. The issue of sensitivity of movement of a target to the left or right can go in either direction. We can justify a person being more sensitive to a target that appears to move in a left to right direction because most of us, at least in the United States, are used to reading from left to right. An argument against that, or if the target moves from right to left, would be that because we are used to seeing objects move from left to right when something moves from right to left we notice it more readily. That is the way that the data fall out; sometimes it goes left to right sometimes it goes right to left. We are introducing modifications in our second series of tests which we hope will provide us with an answer to this question.

COL GIBBONS (US)

When you reviewed the variables you indicated that target image size and low contrast acuity were variables that contributed to detection. Both of those reflect, if you use Snellen acuity to measure them, the visual angle or resolving power of the eye. If this is the case then when we look at contrast sensitivity curves could we not be getting the same thing if we use a contrast testing technique with a Snellen acuity target as opposed to the contrast sensitivity technique with the grading bars that they use?

AUTHOR'S REPLY (CDR MONACO (US))

Yes, I think that that is true. We can relate that same idea to measurements of dynamic visual acuity for example. It has been suggested that instead of using Landolt Cs or tumbling Es that bars of varying spatial frequency can be used to do the same thing. I think that the unique character of our targets is what has allowed us to ferret out the distinction between low contrast acuity and high contrast acuity. I don't think that we would have been so successful if we didn't have finely engineered projection targets and the very high quality control of those targets. but yes I think its very possible to relate contrast sensitivity in terms of spatial frequencies to varying widths of the gap on Landolt Cs. It is something that we hope we will be able to correlate with our contrast sensitivity data when we have an adequate sample size. The test that we are using is very similar to the one that Dr Gray described in his paper.

MÉD EN CHEF SANTUCCI (FR)

First of all I wish to congratulate Dr Monaco for this excellent work. In particular I think that the response time is an important measure because you can characterise the pilot with that test. This study is the beginning of what we can call an integrated test, taking account of and categorising not only the performance of the visual sensor but also the data processing and the decision taking processes. Do you envisage creating new tests with different catergories of colour simulation? In that case would you envisage measuring either the manual response or the verbal response, using the vocal command, of course, which is going to be used more and more in combat aircraft.

AUTHOR'S REPLY (CDR MONACO (US))

(Initial portion of reply not recorded)

I think that the benefit of being in the operational environment and testing these people on site is that you have the opportunity to learn more about what they do which I think is absolutely essential. You have to be able to talk their language and you have to be able to translate what they are saying into meaningful relationships that they can understand and use.

DR ALNAES (NO)

Dr Monaco, I was interested in the very high visual acuity means that these people had. Don't you have any sub population of spectacle wearers? Somebody further down on the range that you could test and compare with these people who fly so magnificently?

AUTHOR'S REPLY (CDR MONACO (US))

Yes we do have data from spectacle wearers but not in the study I reported in my paper. In order to get the test battery ready for use at the range we had to test large groups of people. We have data from nearly 200 subjects who varied not only in visual acuity capabilities but also in terms of amplitude of accommodation. The population of people that we used in our laboratory test had ages ranging from 20 to, I think, approximately 70 years of age. So, yes, we do have that data.

COLONNE VERTEBRALE : SELECTION ET APTITUDE DES PILOTES D'AVION DE COMBAT DU FUTUR

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RESUME : Les nouvelles générations d'avions de combat se caractérisent du point de vue vertébral par la possibilité d'atteindre des accélérations, fortes, instantanées et durables. Pour donner aux pilotes des possibilités optimales d'information visuelle, le rachis cervical conserve sa mobilité et devient vulnérable dans certaines circonstances. Des lésions organiques peuvent survenir en vol sur ce segment. Leur prévention pour assurer la sécurité aérienne met en jeu 3 éléments :
- la sélection rigoureuse basée entre autre en France sur l'exploration radioclinique du rachis et l'application à l'admission du standard d'aptitude des pilotes d'avions de combat avec des adaptations minimes.
- les progrès techniques portant par exemple sur l'allègement du casque
- l'entraînement physique impératif comme une bonne hygiène de vie. Cet entraînement doit être harmonieux, raisonnable et non inutilement perfectionniste pour être régulièrement suivi.

Depuis de nombreuses années, les candidats au personnel navigant de l' Armée de l'Air française subissent une exploration radioclinique de la colonne vertébrale lors de l'expertise d'admission. Outre son aspect médico-légal, son principal intérêt est d'éliminer les candidats porteurs d'anomalie ou de lésion susceptible d'être agravée par le vol et ou de mettre en cause la sécurité des vols. Il convient de fournir au commandement des candidats-pilotes qui aient le maximum de chance de conserver leur aptitude durant la durée de leur carrière.
Les standards d'aptitude sont adaptés aux exigences du pilotage des principaux types d'aéronefs et en particulier aux avions de combat. La mise en service en France d'une nouvelle génération d'avions de combat comme le MIRAGE 2000, doit-elle s'accompagner d'une profonde modification des critères d'aptitude qui concernent le rachis ? Est-il nécessaire de prévoir pour ces pilotes un entrainement physique particulier ?

L'EXAMEN RADIO CLINIQUE DU RACHIS LORS DE L'EXPERTISE D'ADMISSION.

Nous connaissons son but, examinons ses modalités.
L'EXAMEN CLINIQUE apprécie entre autre la statique dans les deux plans, la musculature, l'amplitude, la souplesse et l'indolence des mouvements du rachis.

L'EXAMEN RADIOLOGIQUE comprend :
- soit des clichés d'ensemble face et profil en position debout
- soit des clichés du segment cervical, dorsal, lombo-sacré de face et de profil en position debout, c'est à dire 8 clichés au total avec l'incidence localisée à la charnière cervico-occipitale et lombo-sacrée.

LES PRINCIPES DE PRISE DE DECISION PAR L'EXPERT.

Lorsqu'il découvre une anomalie statique, fonctionnelle, morphologique ou organique, il doit se poser plusieurs questions :
- Cette anomalie met-elle en cause la résistance du rachis aux agressions du vol en particulier lors de l'éjection ?
- Peut-elle se décompenser du fait de l'activité aéronautique et constituer par ses effets secondaires un facteur diminuant la sécurité des vols ?
La réponse à ces questions n'est pas toujours facile. En cas de doute, il vaut mieux être rigoureux à l'admission.

LES CAUSES D'INAPTITUDE.

Il existe des causes d'inaptitude commune à tous les emplois de pilote. Ce sont les affections évolutives de type tumoral, infectieux, inflammatoire et leur séquelle. La quasi totalité des séquelles post traumatiques et les anomalies congénitales complexes sont éliminatoires.
Il faut signaler des causes d'inaptitude spécifique au pilotage des avions de combat.
Les études cliniques et physiopathologiques montrent qu'il existe un segment rachidien critique particulier aux pilotes d'avions de combat. Il s'agit du rachis dorsal et de la jonction dorso-lombaire (éjection).

Les troubles de la statique peuvent favoriser les lésions à l'éjection. Le tableau suivant résume les décisions.

	CONSTATATION	DECISION
Scoliose dorso-lombaire	Angle de scoliose inférieur ou égale à 15°	APTE
	Angle de scoliose supérieur à 15°	INAPTE
Cyphose dorsale	Angle de cyphose inférieur à 35°	APTE
	Angle de cyphose compris entre 35° et 50° (tenir compte de l'association à des séquelles d'épiphysose)	APTE ou INAPTE selon les associations
	Angle de cyphose supérieur à 50°	INAPTE

TROUBLES DE LA STATIQUE VERTEBRALE

Les séquelles d'épiphysose de croissance sont classées en degré.
- degré faible : on note la présence de petites irrégularités et un feuilletage des plateaux vertébraux avec encoche de SCHMORL sans modification de la morphologie générale des vertèbres et de la statique.
- degré moyen : il existe une déformation cunéiforme antérieure d'une vertèbre isolée ou associée aux autres signes plus particulièrement avec des encoches localisées des plateaux et un pincement d'espace intervertébral.
- degré fort : la déformation cunéiforme antérieure intéresse plus d'une vertèbre associée aux autres signes et à un retentissement sur la statique vertébrale.

Le tableau suivant résume les décisions prises.

	CONSTATATION		DECISION
Séquelles d'épiphysose de croissance	Degré faible		APTE
	Degré moyen	dorsal	INAPTE
		lombaire	APTE
	Degré fort		INAPTE

SEQUELLES D'EPIPHYSOSE DE CROISSANCE

La lyse isthmique d'une vertèbre lombaire basse s'accompagnant d'un spondylolisthésis supérieur à 1 cm par rapport à la vertèbre sous jacente, entraine l'inaptitude.

EST-IL NECESSAIRE DE MODIFIER LE STANDARD D'APTITUDE DES PILOTES D'AVIONS DE COMBAT?

Les données du problème.

* les contraintes du poste de travail : les avions de combat de la nouvelle génération et en particulier le Mirage 2000 se caractérisent entre autre par leur aptitude à " virer " court. Ils soumettent le pilote à des accélérations de 8 à 9 G pendant plusieurs dizaines de secondes avec des temps d'installation de celles-ci de l'ordre de la seconde. Les conséquences sur le rachis sont différentes selon que l'on considère le segment dorsal et la jonction dorso lombaire ou le segment cervical.
Le rachis dorso lombaire c'est à dire le tronc bien sanglé et bien soutenu par le dossier du siège éjectable est en mesure de supporter ces accélérations. Le segment dorsal et la jonction dorso lombaire deviennent critiques lors d'une éventuelle éjection.
Le rachis cervical ne bénéficie pas d'appui constant pour conserver à la tête une mobilité nécessaire à la prise des informations visuelles. Ce segment devient critique.

* Anatomie du rachis cervical : il s'agit d'un empilement de segments osseux unitaires de petite taille, mobiles les uns par rapport aux autres. Les vertèbres cervicales sont articulées entre elles et les éléments adjacents antérieurs et postérieurs sont respectivement réunis entre eux par des éléments fibroligamentaires qui assurent un freinage passif à des mouvements complexes qui peuvent être de grande amplitude (flexion, extension, flexion latérale, rotation et leurs combinaisons possibles). La destruction des freins met en danger la stabilité de ce segment rachidien et par conséquent la moelle et les nerfs rachidiens de l'étage cervical.
La succession des articulations disco somatiques antérieures peut être assimilée à une colonne porteuse alors que les articulations interapophysaires postérieures petites et fragiles peuvent être assimilées à des colonettes directrices.
La musculature du cou, système de haubanage actif, assure la mobilité de la tête, le maintien des attitudes, le verrouillage du cou et de la tête en position de stabilité.
En somme, la mobilité de la colonne cervicale permet l'obligatoire prise d'information visuelle du pilote d'avion de combat. Sa fragilité est la rançon de sa mobilité.

* La charge de travail en vol : aux facteurs d'agressions déjà connus, les accélérations Gz intenses de longue durée et brutalement installées ajoutent un élément original.
Le pilote qui s'attend à subir une de ces fortes accélérations, contracte les muscles du cou, verrouille sa tête en position stable et l'on ne constate pas de mouvements anormaux sous accélérations.
Au contraire, si la tête est surprise par une forte accélération en dehors de la position de

verrouillage, son poids apparent dépasse rapidement les possibilités de rattrapage de la musculature ; la tête se mobilise en fonction de l'inverse du sens d'application de l'accélération ; le mouvement va se poursuivre jusqu'à son freinage par les formations anatomiques. Ceci est facile à comprendre si on estime grossièrement le poids de la tête et du cou jusqu'à C6-C7 à 4 Kg et l'équipement de tête à 1,9 Kg, l'ensemble pèse sensiblement 6 Kg. Le poids apparent est de :

30 Kg à 5 G
48 Kg à 8 G
60 Kg à 10 G

La puissance des muscles du cou est rapidement dépassée. Le mouvement non maîtrisé de la tête sous accélération peut être violent et responsable d'un traumatisme crânien contre une paroi de l'habitacle. Le rachis cervical peut être lésé lui même en particulier lorsque la tête est surprise dans une position complexe comme l'extension rotation pour une prise d'information visuelle latérale et haute. Ainsi des entorses, des fractures de ce segment rachidien sont survenues en vol au cours d'accélérations brutales. La survenue d'hernie discale est possible également. De même que le surmenage cervical dû à la répétition des accélérations importantes, est susceptible d'évoluer à la longue vers une décompensation arthrosique.

L'EVOLUTION DU STANDARD D'APTITUDE DES PILOTES D'AVIONS DE COMBAT A L'ADMISSION.

L'application du standard actuel est suffisant sous deux conditions. Il est impératif de bien dissocier les critères propres au pilote de combat et ceux propres au pilote d'hélicoptère et au pilote de transport et de liaison. Il faut ajouter au segment critique classique constitué par le rachis dorsal et la jonction dorso lombaire, le rachis cervical. A ce propos, il faut être particulièrement vigilant quand il existe des antécédents de traumatisme cervical, la moindre séquelle clinique, fonctionnelle, morphologique doit faire prononcer l'inaptitude. Par ailleurs, la découverte d'un bloc congénital entre 2 vertèbres comprises entre C3 et C7 doit amener à pratiquer des épreuves statodynamiques pour juger du retentissement éventuel sur la statique cervicale et l'amplitude des mouvements, si celui-ci est appréciable, l'inaptitude est proposée.

LES ELEMENTS DE PREVENTION DES INCIDENTS CERVICAUX.

Ils sont de 3 types, la sélection, les améliorations techniques, l'entrainement physique.

. La sélection à l'admission doit être rigoureuse comme nous l'avons vu précédemment.

. Les améliorations techniques : la plus simple porte sur l'allègement du casque porté équipement. Il est possible d'imaginer des systèmes capables de laisser une certaine mobilité à la tête tout en assurant en cas d'accélération brutale une contention suffisante à l'ensemble tête-cou. Leur réalisation est probablement complexe pour qu'un tel système soit confortable, donc non dangereux pour le pilote.

. L'entrainement des pilotes : on peut être tenté de renforcer par des exercices particuliers la musculature du cou. Ce serait une erreur, les exercices doivent intéresser l'ensemble de la musculature vertébrale et du tronc sous peine d'un retentissement sur les autres segments rachidiens Le maintien d'une excellente condition physique est nécessaire;pour celà, le respect d'une hygiène de vie et la pratique d'un entrainement physique sont des obligations pour les pilotes. Pour qu'un entrainement physique qui intéresse l'appareil locomoteur et le rachis, le système cardio respiratoire, l'amélioration des réflexes, soit régulièrement suivi, il est nécessaire qu'il soit raisonnable et suffisamment attrayant. Des efforts dans ce sens sont faits.

CONCLUSION.

La prise d'information visuelle est plus que jamais nécessaire dans le combat aérien avec les nouvelles générations d'avions de combat. Elle est possible grâce à la mobilité du rachis cervical, sa rançon c'est une certaine fragilité. Ce segment rachidien devient critique.
L'exploration radioclinique et le standard d'aptitude à l'admission des futurs pilotes d'avions de combat est adapté en ce qui concerne le rachis à une sélection qui doit être rigoureuse pour être efficace.
Les progrès techniques comme l'allègement du casque, la mise au point du système de contention, peuvent améliorer la résistance à ces contraintes nouvelles.
Une hygiène de vie et un entrainement physique harmonieux et non inutilement perfectionniste doivent être considérés comme un devoir pour les pilotes d'avions de combat du futur.

SYSTEMATIC RADIOGRAPHIC EXAMINATION OF THE SPINE FOR SELECTION OF F-16 PILOTS: A PRELIMINARY REPORT

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ABSTRACT.

With the introduction of the high performance aircraft F-16 in the Royal Netherlands Air Force an increase in spinal column disorders was anticipated. Therefore, a sytematical radiographic whole spine examination of Candidate Student Pilots (CSP's) and Qualified Pilots (QP's) designated to fly F-16 has been performed since december 1982. To reduce radiation exposure radiographs were made using a modern 14 inch intensifier. Sofar, 225 CSP's and 196 QP's have been examined.
Strict application of the medical criteria leads to a rejection of 20 % of the CSP's because of spinal disorders visualised on X-ray.
For F-16 pilots, the major region of interest seems to be the cervical spine.
The rejection rate could be reduced by readjustment of the medical criteria and separate selection of helicopter and fighterpilots.
Systematic examination of QP's who had no or incomplete previous examinations uncovers a high rate of spinal disorders.
In our series QP's without symptoms were only rejected because of cervical discopathy with osteophyte formation on the backside of the vertebrae and resulting narrowing of the spinal canal.

INTRODUCTION

Spinal column disorders affect a significant segment of the airforce pilots and are at one time or another a major cause of pain, weakness and impaired endurance (6).
With the introduction of the high performance aircraft F-16 in the Royal Netherlands Air Force (RNLAF) a considerable increase of spine symptoms was expected by the medical authorities. Therefore, the need for a systhematic radiographic examination of the whole spine of both Candidate Student Pilots (CSP's) and Qualified Pilots (QP's) designated to fly F-16 was strongly felt. This examination has been performed since november 1982.

METHODS, RADIATION HAZARDS AND MATERIALS.

An adequate radiographic examination of the whole spine includes a considerable number of photographs. This results in a substantial radiation exposure to the examinee.
In this study the standard examination includes the following 10 radiographs.

4 Lumbosacral spine: Postero-anterior, lateral and two oblique projections

2 Thoracic spine : Antero-posterior and lateral

3 Cervical spine : Postero-anterior, lateral at rest and in flexion and extension.

This examination performed with conventional X-ray equipment gives a radiation exposure of about 650 m rem to the bone marrow (4). This organ dose is five times the average yearly doze of natural radiation of 130 mrem (sea level). According to the data of the International Committee of Radiation Protection (7), this dose of 650 mrem may lead to a tumour induction frequency of 0.13 0/00 with a latent period of 5 to 20 years. Statistically this cannot be measured because of the fact that the spontaneous tumour incidence frequency is about 24 %.
Full-spine radiography (the whole spine on one photograph in AP projection and one in lateral projection) can reduce the radiation exposure to 115 mrem (5). In our opinion however, this method is excellent for measurement of scolioses but inadequate to trace a variety of spinal disorders.
Substantial reduction of radiation can also be achieved by using a modern 14 inch image intensifier to make the radiographs. Compared with conventional radiography this method allows a 4 to 10 times reduction of exposure, depending on the more or less use of fluoroscopy for positioning of the examinee.
The resulting small size pictures (10 x 10 cm) are of good quality an sufficient for any radiological interpretation except a very accurate measurement of the angle of a scoliosis. In our experience however, this restriction never posed a problem.
The radiographs were interpreted by a radiologist, when in doubt an orthopedic surgeon was consulted to give a 'second' opinion. Aeromedical disposition and waiver authority were the responsibility of the Director Aviation Medicine Division.

Since november 1982 all CSP's are subjected to the previously described examination at the end of the selection procedure.
All accepted CSP's will be reexamined after six years. The CSP's who were rejected during the training period will also be reexamined as far as possible and will function as control group. Furthermore all QP's designated to fly F-16 are examined.
This examination will also be repeated after six years unless disorders are found which require a more frequent follow-up observation.

RESULTS.

Up to 1-1-1985 225 CSP's were radiographically examined. Strict application of the Flight Medical Standard (FMS) of the RNLAF led to rejection of 45 candidates. The reasons for rejection are listed in table 1. Candidates with signs of Scheuermann's disease were rejected when there were more than two obvious Schmorl's nodules. Also a unilateral spondylolysis or a spina bifida occulta with two or more vertebrae involved was reason for rejection.

Table 1.

N = 225	100 %	Number of CSP's examined.
45	20 %	Rejected for spinal disorders visualised by radiography.
22	10 %	vertebral osteochondritis (Scheuermann's disease)
13	6 %	spondylolysis/lysthesis
5	2 %	congenital anomalies
3	1 %	discopathies
2	1 %	other disorders

So far, 196 qualified fighter pilots underwent the whole spine examination before they were allowed to be certified for the F-16. In the past, only some individuals of this group had been radiographically examined.
The results are listed in the following table.

Table 2.

N = 196	100 %	number of qualified pilots examined
97	49 %	no or very slight disorders
99	51 %	one or more disorders, listed below
65	33 %	thorocolumbar disorders:
21	11 %	Scheuermann's disease: 12 slight 9 moderate
19	10 %	lysis / lysthesis lumbar
12	6 %	lumbar discopathy, 1 status after laminectomy
2	1 %	status after moderate compression fracture Th 12 / L 1
8	4 %	congenital anomalies, 6 of these transitional vertebra
3	2 %	osteo-arthritis thoraco-lumbar, rather advanced.
48	24 %	cervical disorders:
16	8 %	abnormal alignment, uncomplicated
9	5 %	cervical discopathy, uncomplicated
18	9 %	cervical discopathy with osteophytes
5	3 %	cervical osteo-arthitis, uncomplicated

DISCUSSION.

In our series, 20 % of the CSP's were rejected because of radiographically visualised spinal disorders whether they had symptoms or not. In the period prior to our study (1980 and 1981), only 'full spine' radiographs were made which led to rejection of 7.5 % of the CSP's. This marked increase is partly due to the more detailed radiographic information obtained by our method. However, it also resulted from the readjustment of the RNLAF FMS to the more strict criteria for high performance aircraft pilots as recommended by Kazarian (6).
Another reason for the high rejection rate is the fact that in the RNLAF the CSP's have to be medically qualified for fighter pilot as well as helicopter pilot. For various reasons aircraft choice is made later on.
Delahaye (2) advises to reject helicopter CSP's who show transitional lumbo-sacral anomalies associated with asymmetry, marked disengagement of the pivot vertebra, or transversosacral new joint formation. In our series, this anomaly by itself was no reason for disqualification. Otherwise, the rejection rate would even have been higher.
Operational experience with the F-16 suggest that in comparison with their previous aircraft (F-104 and NF-5), F-16 pilots have less lumbar spine symptoms but complain far more about cervical pain and discomfort.
In a limited study, Aghina (1) found that F-16 pilots had 8 times more cervical symptoms than F-104 pilots. At one time or another, 67 % of the F-16 pilots had experienced cervical symptoms during the observation period of half a year. Similar observations were reported by other RNLAF flight surgeons. This is partially due to the extreme G-acceleration possibilities of the F-16 aircraft. It is also related to the different body position in the F-16 where the thoracolumbar spine leans backward at an angle of 30°, requiring a correctional flexion of the cervical spine.
Because of the awareness of the extreme strain on the cervical spine, special attention was given to this part of the examination. However, disorders of the cervical spine were reason for rejection of only 4 CSP's (2 %). Moderate disalignment with normal flexion and extension was in our series no reason for disqualification.
In contrast, for helicopter pilots the lumbar spine is known to be the most vulnerable part. Therefore, the introduction of high performance aircraft will probably lead to an increasing discrepancy between the medical qualification criteria for fighter and helicopter pilots. In particular after a possible readjustment of the FMS, this should be reason for separate selection even in small airforces, in order to reduce the rejection rate.
In this respect, the recommendations of Delahaye (2) about different criteria for helicopter and fighter pilots and his opinion about spina bifida occulta as an innocent anomaly have to be mentioned.

The radiographic examination of 190 QP's showed in 70 cases spinal disorders which according to the RNLAF FMS should be reason for disqualification. Without doubt, the resulting rejection rate of 36 % of the QP's was inacceptable in our opinion.
Discussion between flight surgeons, radiologists and orthopedic surgeons led to the conclusion that qualified fighter pilots with no symptoms restricting operational employment should be rejected only when an unacceptable increased risk to their physical health, or an obvious increased risk for flight safety could be assumed.
With this point of view as the guideline, lumbar an thoracic spine disorders were in no case of our series reason for rejection.
One F-16 pilot who received a waiver for a spondylolysthesis, three month later experienced an inflight ejection followed by a rough parachute landing. On X-ray a slight compression fracture of L-1 was shown. In spite of this, the lysthesis of L-5 was completely unchanged in comparison with previous radiographs. The stability of a lysthesis seems to be adequate to resist severe trauma in most cases (3).
Reason for serious concern were long existing discopathies of the cervical spine with osteophyte formation, in particular when osteophytes were located on the back side of the vertebrae. This causes a narrowing of the cervical canal and may lead to compression of the myelum.
In clinical medicine a minimal diameter of the cervical canal of 14 mm (as measured on a standard lateral radiograph) is assumed to be sufficient for the myelum. However, there is much uncertainty about the possible risk of a sudden fracture of an osteophyte during the extreme G-strain which can be achieved in the F-16. When the osteophyte is located on the back side of the cervical canal an acute compression of the myelum with resulting paralysis could be expected in case of a fracture.
In our series of 18 cervical discopathies with osteophyte formation, four pilots were definitely rejected for F-16 and three pilots received a G-restriction.
All pilots with cervical discopathy who had been granted a waiver for the F-16 were designated for a yearly radiographic follow-up examination.

CONCLUSIONS.

1. Systematic radiographic examination of the whole spine leads to a high rejection rate of CSP's.

2. Radiographic examination of QP's with no or incomplete previous examinations uncovers a high rate of spinal disorders.

3. In QP's designated to fly F-16, the cervical spine is the major region of interest. In our opinion, tracing of disorders on this level will substantially attribute to flight safety.

4. The introduction of high performance aircraft as F-16 will probably lead to an increasing discrepancy between the desirable criteria for fitness as a fighter or helicopter pilot, as far as the spine is concerned. In our opinion the cervical spine is the most vulnerable part in F-16 pilots as for helicopter pilots it is the low back. However, readjustment of the RNLAF FMS will depend on further investigations. Together with separate selection of fighter and helicopter pilots this could reduce the rejection rate of CSP's.

5. Finally, performance of the examination by use of image intensifier radiography can markedly reduce radiation exposure.

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DISCUSSION OF SESSION V - MEDICAL SELECTION: THE SPINAL COLUMN
(Papers 40 and 41)

DR ALNAES (NO)

Maj Van Dalen, what is your protocol for follow up radiography of F-16 pilots that you now have base line X-rays on? When is the next time that you have a look at those cervical spines?

AUTHOR'S REPLY (MAJ VAN DALEN (NL))

We plan for the pilots to return for another X-ray examination after 6 years unless anomalies or disorders are found that require an earlier follow up. All the pilots with cervical disc pathology and osteophyte formation come back every year for a picture of the cervical spine to see if the osteophytes have increased in size. I think that when the increase in osteophytes has narrowed the spinal canal to 14 mm we should reject the individual for flying the F-16. There is, however, little in the literature about this subject and we are still a little unsure. We are conducting biomechanical studies in Holland to see where the weak places are on the cervical level. We hope to be able to answer the serious question - can high G strain produce an acute avulsion fracture of an osteophyte on the rear surface of a vertebral body? Is that possible or not?

DR DURAS (FR)

Regarding cervical disc disease, it is well established that plain X-ray findings do not correlate well with clinical problems and I wonder how valid is this straight X-ray examination?

AUTHOR'S REPLY (MAJ VAN DALEN (NL))

It is indeed true that you can have severe cervical disorders like disc pathology with osteophyte formation without any symptoms. We have many pilots with very advanced disorders who have no symptoms. We don't know where the disc pathology has broken out - is it on the lateral side of the vertebra or on the posterior suface where the nerves are? However, although the spinal cord can adapt to some AP narrowing of the spinal canal without apparent interference with function, a sudden gross reduction in the width of the canal will produce compression of the cord with severe neurological symptoms. The problem with which we are faced is the possibility that during flight when an F-16 pilot is exposed to very high G the cervical cord may be suddenly compressed.

COL VAN DEN BIGGELAAR (NL)

I would like to comment on Dr Van Dalen's remarks. Fighter pilots flying in the rear seats of dual control aircraft report that when the pilot in the front seat applies G, even only 4-5 G, without warning he may suffer a sudden deflection of the head so that the pilot really strains his neck. Now if this is the neck of a pilot without any clinical complaints but with a very narrow spinal canal, damage to the cord could well occur. We know that 60% of our F-16 population regularly have neck problems for which they see a flight surgeon. This is a very critical area and we are very worried for the future.

ENTRAINEMENT PHYSIQUE DES PILOTES DE MIRAGE 2000

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RESUME

Neuf pilotes de combat ont suivi un entraînement physique spécifique à base de musculation en vue d'améliorer leur tolérance aux fortes accélérations. La validation de cet entraînement a été recherchée par des tests en centrifugeuse. Le gain de tolérance objectivé peut être attribué respectivement ou conjointement à l'entraînement, à l'adaptation à la centrifugeuse et à une meilleure efficacité des manoeuvres type M1.

INTRODUCTION :

Volant sur les avions de combat de la nouvelle génération (type MIRAGE 2000), les pilotes sont soumis lors de certaines phases du vol à des accélérations soutenues, de haut niveau, variant rapidement en sens et en intensité. Dans ces conditions, les seuils classiques d'apparition des troubles visuels (voiles) sont rapidement atteints voire même dépassés ; des pertes de connaissance brutales sans signes précurseurs peuvent survenir, des pétéchies, des troubles du rythme cardiaque et des cervicalgies ont pû être observés.

Pour améliorer la tolérance des pilotes à cette contrainte, on a cherché à améliorer les moyens de protection classiques : pantalon anti-g, siège incliné, manoeuvres d'anticipation volontaires, manoeuvres respiratires etc... Tous ces moyens ont une efficacité certaine et prouvée, mais il apparaît que le maintien d'une bonne condition physique et un entraînement spécifique constituent des atouts indispensables. Ce type d'entraînement a été défini et mis au point ; on a cherché à le valider par une expérimentation.

PRINCIPES DE L'ENTRAINEMENT :

Inspiré des travaux d'EPPERSON, cet entraînement a pour principe d'associer à une préparation physique générale des exercices spécifiques et une gymnastique vertébrale.

1 - **Préparation physique générale** : c'est une préparation de base visant à améliorer les qualités **d'endurance** : l'organisme travaille en aérobiose en soutenant des efforts d'intensité faible pendant des temps assez longs. Dans cette optique, plusieurs variantes peuvent être proposées : footing, ski de fond, natation etc... Qelle que soit la modalité choisie, cette préparation doit se faire en dehors de tout esprit de compétition.

2 - **Préparation physique spécifique** : elle a pour but d'améliorer les qualités de **résistance** musculaire à des efforts soutenus d'intensité forte, l'organisme travaillant en anaérobiose. Ces exercices intéressent la plupart des grands groupes musculaires pouvant améliorer l'efficacité des manoeuvres respiratoires du type M1 et assurer un meilleur haubanage de la colonne vertébrale.

3 - **Gymnastique vertébrale** : son but est de développer la musculature paravertébrale afin de minimiser les rachialgies notamment cervicales.

EXPERIMENTATION :

Mis au point avec la collaboration de quelques pilotes et d'un moniteur des sports, ce programme d'entraînement a fait l'objet d'une expérimentation pour en valider l'efficacité.

1 - **Sujets** : Neuf pilotes ont participé à l'expérimentation. Tous volontaires et très motivés, ces pilotes cadres moniteurs d'une unité d'entraînement au combat, avaient en moyenne 1800 heures de vol et étaient âgés de 30 ans.

2 - **Entraînement** : suivant les principes énoncés précédemment, il comportait :

1°/ un footing cardiovasculaire hebdomadaire : effectué en décontraction, à petits pas rythmés par la respiration sur une distance de 5 km environ.

2°/ des exercices musculaires exécutés dans une salle spécialement aménagée à raison de deux séances par semaine. Chaque séance comporte la répétition de 10 exercices, chacun consistant en trois séries de 10 mouvements, effectués selon une chronologie bien codifiée. L'appellation de ces exercices est la suivante :

1 . TRACTIONS DES BRAS DEBOUT	6. FLEXIONS BRAS/AVANT-BRAS
2 . DEVELOPPE COUCHE	7. EXTENSIONS BRAS/AVANT-BRAS
3 . RENVOIS AUX BRAS PLIES	8. EXTENSIONS JAMBE/CUISSE
4 . TRACTIONS DES BRAS PENCHE	9. EXTENSIONS COMPLETES JAMBE/CUISSE
5 . TRACTIONS ARRIERE ASSIS	10. ABDOMINAUX

Pour chaque exercice un poids maximum de charge additionnelle (PM) est défini. Cette charge fonction du poids du sujet, est atteinte progressivement en 10 semaines en respectant un tableau de marche précis. L'initiation à cette musculation et le suivi de l'entraînement sont confiés à un moniteur spécialisé.

3°/ une gymnastique vertébrale consistant en quelques mouvements d'assouplissement classiques exécutés quotidiennement. Le tableau ci-dessous récapitule les caractéristiques de cet entraînement :

TYPE ENTRAINEMENT	BUT RECHERCHE	RECOMMANDATIONS	FREQUENCE DUREE
FOOTING	ENDURANCE	ALLURE MODEREE	1 à 2 FOIS / SEMAINE 1 HEURE
MUSCULATION	RESISTANCE PUISSANCE	PROGRESSIVITE REGULARITE	2 FOIS/SEMAINE/3 MOIS PUIS 1 FOIS/SEMAINE 1 HEURE 15 / SEANCE
GYMNASTIQUE VERTEBRALE	HAUBANAGE VERTEBRAL	REGULARITE	15 MINUTES / JOUR

3 - **Critères d'appréciation** : pour objectiver l'efficacité de l'entraînement sur la tolérance aux accélérations :

1°/ tests en centrifugeuse : deux tests ont été effectués au Laboratoire de Médecine Aérospatiale T1 et T2 avant et après 10 semaines d'entraînement spécifique. Les pilotes étaient porteurs de pantalon anti-g et le siège nacelle était incliné à 18°. On a utilisé la technique du "GOR" : accélérations de 0,1 g/seconde. La fin de l'épreuve était décidée soit par le sujet lui-même lorsqu'il pensait avoir atteint la limite de tolérance volontaire maxima, soit par l'expérimentateur lorsqu'une amputation de 50 % du champ visuel périphérique était constatée ou à l'apparition éventuelle de troubles du rythme cardiaque.

La veille de chaque test, les sujets étaient familiarisés avec la centrifugeuse par deux lancements effectués sans pantalon anti-g, avec une accélération de 0,3 g/seconde jusqu'à une mise en plateau d'une minute à 3 et 5 g.

2°/ Paramètres physiologiques : Au cours des différents tests on a suivi l'évolution de :

- la fréquence cardiaque.
- la pression artérielle systolique et diastolique.
- la saturation artérielle en O2.
- le champ visuel périphérique.

4 - Résultats :

1°/ Tests en centrifugeuse : dans le tableau ci-dessous on a mentionné pour chacun des sujets les niveaux (en g) d'accélération atteints lors des deux tests : T1 et T2. Dans la grande majorité des cas la fin de l'épreuve a été déterminée par le sujet lui-même.

SUJETS	T_1	T_2
1	9,5	9,4
2	6,2	9,8
3	7,7	8,8
4	8,8	10,5
5	9,3	11,3
6	8,5	9,3
7	9,2	10,8
8	8,8	10,8
9	8,0	9.8
$\bar{m}$ $\pm$ s	8,73 $\pm$ 0,59	10,06 $\pm$ 0,84

Pour tous les sujets, sauf le premier, on observe une augmentation nette de la tolérance aux accélérations : le gain moyen entre T2 et T1 = 1,33 g (t = 5,31 - S.01).

2°/ Paramètres physiolgiques : on a enregistré leur évolution en fonction des niveaux d'accélération atteints.

* Fréquence cardiaque : moyenne $\pm$ écart type.

G	T_1	T_2	t	S
REPOS	77,4 $\pm$ 10,5	82 $\pm$ 8,1	1,236	NS
2	98,2 $\pm$ 16,3	125,7 $\pm$ 20,6	4,648	0.1
3	115,4 $\pm$ 16,2	130,4 $\pm$ 17,6	4,445	0.1
4	123,8 $\pm$ 19,6	138,6 $\pm$ 20,8	4,108	0.1
5	127,8 $\pm$ 20,4	142,2 $\pm$ 19,0	2,945	0.2
6	137.3 $\pm$ 18,9	150,6 $\pm$ 21,13	3,46	0.2
7	140 $\pm$ 18,3	154,1 $\pm$ 20,2	3,05	0.2
8	143 $\pm$ 18,9	154,6 $\pm$ 20,1	1,13	NS
9	141	155,7 $\pm$ 21,4		
10		153,5 $\pm$ 22,8		

On observe dans les deux situations une accélération classique de la fréquence cardiaque. Bien que partant d'une valeur de repos plus élevée, cette augmentation de rythme paraît plus importante lors de T2 et une différence significative est mise en évidence pour à peu près tous les niveaux d'accélération.

* Pression artérielle systolique et diastolique : le calcul n'ayant pas mis en évidence de différence significative entre T1 et T2, les résultats ne sont pas détaillés. On retiendra seulement :

- en ce qui concerne la pression systolique elle évolue en moyenne ainsi :

T 1 : repos : 12,4 cm Hg ± 0,63.... 8 g : 19,1 cm Hg ± 0,96.

T 2 : repos : 12,0 cm Hg ± 1,63.... 8 g : 18,8 cm Hg ± 1,22.

Pour tous les niveaux d'accélération, les valeurs de la PA systolique à T2 sont toujours légèrement inférieures à celles de T1.

- en ce qui concerne la pression diastolique, son évolution moyenne est comparable :

T 1 : repos : 7,4 cm Hg ± 0,74.... 8 g : 13,3 cm Hg ± 1,89.

T 2 : repos : 7,22 cm Hg ± 0,67... 8 g : 11,8 cm Hg ± 2,25.

On observe une augmentation progressive de la PA diastolique et les valeurs de T2 sont toujours légèrement inférieures à celle de T1.

* Saturation artérielle 02 : il n'existe aucune différence significative entre T1 et T2. On retiendra que la saturation artérielle en 02 baisse progressivement en fonction du niveau d'accélération :

T 1 : repos : 97,4 % ± 1,33.... 10 g : 80,25 % ± 8,54.

T 2 : repos : 99,7 % ± 1,16.... 10 g : 85,8 % ± 5,9.

* champ visuel : on a suivi l'évolution du retrécissement du champ visuel périphérique. En l'absence de différence significative entre T1 et T2 on retiendra que :

T 1 : le champ visuel reste inchangé (180°) jusqu'à 4 g ; une amputation commence à se dessiner par la suite et le champ se réduit à 164°,4 ± 21,8 à partir de 7 g.

T 2 : l'intégrité du champ visuel est conservée jusqu'à 6 g ; par la suite on observe un retrécissement progressif, le champ couvre encore 171°,1 ± 14,5 à 9 g.

5 - **Discussion** : Ces résultats appellent les commentaires suivants :

- en ce qui concerne les tests en centrifugeuse, on peut être surpris de constater que, au départ, (T') tous les sujets ont une tolérance élevée aux accélérations. Il faut rappeler que ces sujets, tous volontaires et très motivés, faisaient partie d'une unité spécialisée à l'entraînement au combat et étaient des "professionnels du g". Malgré ce niveau de référence élevée, on constate, lors de T2, une amélioration sensible et significative de la tolérance aux accélérations (1,33 g en moyenne).

- en ce qui concerne les paramètres physiologiques, l'étude de leur évolution montre qu'il existe une différence entre T1 et T2 mais cette différence n'est jamais significative sauf pour la fréquence cardiaque.

Dans ces conditions on peut formuler [illegible]palement deux hypothèses pour expliquer l'amélioration de la tolérance en centrifu[illegible]. Il peut s'agir :

. soit d'une adaptation physiologique réelle mais les paramètres enregistrés ne permettent pas de vérifier cette éventualité.

. soit d'une adaptation des sujets à la technique très particulière de la centrifugeuse : habituation ou apprentissage.

Dans les deux cas, il est permis d'évoquer une efficacité accrue dans l'exécution des manoeuvres respiratoires pouvant être due aussi bien à l'entraînement spécifique qu'à une accoutumance à la centrifugeuse.

CONCLUSIONS :

Après un entraînement spécifique associant un footing, des exercices de musculation et une gymnastique vertébrale, les 9 pilotes ont amélioré sensiblement leur tolérance aux accélérations. Les enregistrements physiologiques effectués : fréquence cardiaque, pression artérielle systolique et diastolique ne semblent pas en faveur d'une adaptation cardiovasculaire pouvant être à l'origine de ce gain.

Par contre, une simple adaptation à la centrifugeuse ne peut être éliminée tout au moins comme cause favorisante. Une expérimentation complémentaire avec un groupe témoin et si possible l'enregistrement des pressions intrathoraciques permettra de justifier pleinement l'efficacité éventuelle de l'entraînement spécifique proposé.

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SPIROERGOMETRIE SUR TAPIS ROULANT DANS LA SELECTION ET LA SURVEILLANCE DES PILOTES D'AVIONS A HAUTES PERFORMANCES DE LA FORCE AERIENNE BELGE

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SOMMAIRE

Tous les pilotes de la Force Aérienne Belge, désignés pour leur conversion sur les avions F-16, sont soumis à des examens cardiovasculaires et respiratoires : l'un d'entre-eux est le test d'effort maximal sur tapis roulant.

Dans une première étude, nous avons rassemblé les résultats de ce screening et ceux d'une série de tests effectués chez un groupe de jeunes candidats élèves-pilotes et avons pu ainsi réaliser une évaluation de la capacité aérobique ($\dot{V}O_2MAX$) de notre population belge. L'échantillon testé est constitué de 156 personnes d'âges différents et de degré d'entrainement variables. Chez chaque individu, la $\dot{V}O_2MAX$ $mlkg^{-1} min^{-1}$ et la pente d'accroissement de la $\dot{V}O_2$ $mlkg^{-1} min^{-2}$ ont été mesurées pendant l'exercice : ce sont des valeurs observées.

Dans une seconde étude, nous avons observé l'effet favorable de l'entrainement physique régulier sur les résultats de la spiroergométrie sur tapis roulant chez un groupe (N = 20) de pilotes F-16, qui avait enregistré, lors d'un premier test, un résultat peu élevé de $\dot{V}O_2MAX$.

MATERIEL ET METHODES

Le matériel technique utilisé comprend :
- une colonne de spiroergométrie SIREGNOST FD 85S (SIEMENS) composée d'un spiromètre électronique à pneumotachographe et d'un analyseur d'anhydride carbonique à rayons IR,
- un analyseur d'O_2 BECKMAN OM11 à système de mesure électrochimique,
- un électrocardiographe à 6 canaux ELEMA-SCHONANDER, MINGOGRAF 61, connecté à un électrocardioscope à 4 canaux de la même marque,
- un tapis roulant QUINTON 18-54 dont la vitesse varie de 0 à 16 km/h et la pente de 0 à 25 %.

Les appareils précédents sont reliés au moyen d'un convertisseur analogique-digital (A-D) à un calculateur programmable TEKTRONIX 31. En effet, ces appareils d'enregistrement des paramètres indispensables à la spiroergométrie émettent des signaux analogiques vers le convertisseur A-D, qui les transforme en sorties digitales (outputs) en vue de leur introduction dans le calculateur.
Le programme de spiroergométrie a été mis au point par le Médecin Colonel J. CLEMENT (BE).
La calibration du convertisseur A-D et des appareils d'enregistrement est effectuée selon les principes suivants : les valeurs des sorties digitales (outputs) constituent des fonctions plus ou moins linéaires mais inconnues des grandeurs mesurées, c.à.d. : vitesse de déroulement et pente du tapis, volume expiratoire minute, concentrations de CO_2 et d'O_2 dans l'air expiré. La forme de chaque fonction est d'abord établie empiriquement à l'aide de grandeurs connues : vitesses et pentes du tapis préchoisies, mélanges gazeux déterminés d'O_2 et de CO_2, volume expiratoire simulé à l'aide d'une pompe d'étalonnage. Ensuite elle est traduite en équation algébrique suivant une méthode de statistique connue sous le nom de régression polynomiale. Cette méthode fournit des coéfficients d'étalonnage, qui introduits dans le programme d'ergométrie, permettent de retrouver une grandeur d'entrée inconnue à partir d'un signal digital "observé" par le calculateur. Elle permet en outre de corriger efficacement les diverses sources de non-linéarité dans les réponses des appareils d'enregistrement et de transmission. La validité des coéfficients d'étalonnage est régulièrement vérifiée, par réitération du programme de vérification de la calibration (12). La calibration des analyseurs de gaz s'effectue au moyen de mélanges de gaz étalons de grande précision : mélange N°2 d'AIR LIQUIDE contenant : O_2, CO_2, N_2. La concentration de ces gaz ne peut varier que de ± 1 %.

La méthode spiroergométrique utilisée est celle de R.A. BRUCE (4) avec effort maximal sur tapis roulant. Le sujet testé est présélectionné par un examen clinique complet : RX du thorax, ECG au repos et des épreuves de la fonction respiratoire incluant la mesure du volume résiduel. Pendant le test, le sujet respire en circuit ouvert au moyen d'un masque appliqué hermétiquement sur le visage.
Les gaz expirés sont récoltés dans le bac mélangeur du SIREGNOST. La charge imposée au sujet est accrue toutes les trois minutes, sans interruption de la course, suivant le protocole de R.A. BRUCE. La progressivité choisie permet d'obtenir un accroissement quasi-linéaire de la consommation d'oxygène ($\dot{V}O_2$). L'épreuve est arrêtée lorsque la capacité aérobique maximale ($\dot{V}O_2MAX$) est atteinte. Deux critères physiologiques : la fréquence cardiaque et le quotient respiratoire) (QR) permettent d'apprécier si la $\dot{V}O_2MAX$ est atteinte. Toutes les minutes de l'épreuve, les paramètres suivants sont affichés par le calculateur : la charge en watts ; le volume expiré par minute (VEM) en litres min^{-1} BTPS ; la $\dot{V}O_2$ en litres min^{-1} et $mlkg^{-1} min^{-1}$ STPD : la $\dot{V}CO_2$ en litres min^{-1} STPD ; la fréquence respiratoire min^{-1} (RF) ; le quotient respiratoire (QR) ; l'équivalent respiratoire (RE) ; la fréquence cardiaque (FC) et le pouls d'oxygène en ml.

L'étude statistique initiale est réalisée sur un échantillon de 156 individus de sexe masculin, comprenant aussi bien des sujets physiquement entrainés que d'autres n'exerçant un sport qu'à titre occasionnel ainsi que quelques sédentaires. Environ la moitié de cet échantillon est constituée par des candidats élèves-pilotes et l'autre moitié par des candidats pilotes F-16.

RESULTATS ET DISCUSSION

Dans notre première étude (19) consacrée à l'établissement de normes au moyen d'un échantillon de 156 personnes d'âges différents et de degré d'entrainement variables, nous avons observé les résultats suivants dont les moyennes ($\bar{X}$ ± SD) des paramètres ergométriques et biométriques sont rassemblés dans le Tableau I.
Nous avons comparé ces résultats avec ceux de R.A. BRUCE (USA) et de BANG LEE HO (TAIWAN) utilisant la même méthode de BRUCE et compte tenu des différences d'âge et de poids entre les trois échantillons, la correspondance est assez bonne. Un autre comparaison entre nos résultats et ceux de MYLES W.S. et TOFT R.J. (15) utilisant le test non interrompu de TAYLOR et ceux de PATTON J.F., VOGEL J.A. et MELLO R.P. (16) utilisant le test

interrompu de TAYLOR-MITCHELL a été réalisée. Ici également, compte tenu des moyennes de l'âge et du poids des échantillons examinés, la correspondance est bonne : voir le Tableau II.

AGE ans	TAILLE cm	POIDS kg	PENTE $\dot{V}O_2$ $mlkg^{-1}min^{-2}$	VO_2MAX $lmin^{-1}$	VO_2MAX $mlkg^{-1}min^{-1}$	VE ou RMV $lmin^{-1}$	FC min^{-1}	DUREE min	CHARGE watts
25,82 $\pm$ 6,77	176,84 $\pm$ 5,58	72 $\pm$ 9,4	2,613 $\pm$ 0,439	3,75 $\pm$ 0,57	52,1 $\pm$ 7,04	111 $\pm$ 19	184 $\pm$ 12,5	15,5 $\pm$ 2	304,6 $\pm$ 58,6

<u>TABLEAU I</u> : SPIROERGOMETRIE SUR TAPIS ROULANT A LA B.A.F. : PARAMETRES ERGOMETRIQUES ET BIOCHIMIQUES OBSERVES : $\bar{X} \pm SD$ (N = 155).

AUTEURS	BRUCE R.A (USA)	C MED FAE (BE)	LANG LEE HO (TAIWAN)	MYLES (UK)	PATTON (USA)
METHODES	BRUCE	BRUCE	BRUCE	TAYLOR	TAYLOR-MITCHELL
AGE : années	35,1 $\pm$ 7,4	25,82 $\pm$ 6,77	43,1 $\pm$ 11,5	25,4 $\pm$ 5,2	26,3 $\pm$ 1,4
POIDS : kg	79,5 $\pm$ 7,4	72 $\pm$ 9,4	64,4 $\pm$ 8,8	70,2 $\pm$ 8	71,9 $\pm$ 2,1
VO_2MAX OBS $mlkg^{-1}min^{-1}$	49,7 $\pm$ 6,7	52,1 $\pm$ 7,04	40,5 $\pm$ 6,9	52,7 $\pm$ 6,1	53,1 $\pm$ 1,9
FC ou fréquence cardiaque min^{-1}	182 $\pm$ 10	184 $\pm$ 12,5	163,1 $\pm$ 12,6	-	188 $\pm$ 2
DUREE en min	12,5 $\pm$ 2,6	15,5 $\pm$ 2	13 $\pm$ 2	-	-
N = nombre de sujets	13	156	24 x 3 = 72	31	15

<u>TABLEAU II</u> : COMPARAISON DE 5 ETUDES DE SPIROERGOMETRIE SUR TAPIS ROULANT SELON DIVERSES METHODES : $\bar{X} \pm SD$.

Par un programme de régression multiple, nous avons constaté que seuls les paramètres poids et âge étaient les mieux corrélés avec le $\dot{V}O_2MAX$ $mlkg^{-1}min^{-1}$ et que seul le paramètre âge était bien corrélé avec la pente de la $\dot{V}O_2$ $mlkg^{-1}min^{-2}$. Les équations de régression (a) et (b) permettent de calculer les valeurs prédites (normes) de notre échantillon (N = 156) : voir le Tableau III.

VO_2MAX PRED $mlkg^{-1}min^{-1}$ = 70,29-0,125.(poids kg)-0,356.(âge ans) $\pm$ 6,375 (DSR)	(a)
PENTE $\dot{V}O_2$ PRED $mlkg^{-1}min^{-2}$ = 3,2417-0,02435.(âge ans) $\pm$ 0,4062 (DSR)	(b)

<u>TABLEAU III</u> : TEST DE BRUCE A LA B.A.F. : FORMULES DE PREDICTION (NORMES).

Les déviations standards résiduelles (DSR) sont respectivement : 6,375 $mlkg^{-1}min^{-1}$ pour la $\dot{V}O_2MAX$ et 0,4062 $mlkg^{-1}min^{-2}$ pour la pente. Ces équations (a) et (b) peuvent être utilisées comme normes: leurs valeurs prédites de $\dot{V}O_2MAX$ kg^{-1} et de pente-1,95 % DSR peuvent être adoptées comme seuils inférieurs de la normalité ($p < 0,05$).

Sur le même échantillon, nous avons calculé les corrélations entre les valeurs de $\dot{V}O_2MAX$ kg^{-1} observées et les valeurs prédites soit à l'aide de notre formule (a) soit à l'aide de la formule de prédiction correspondante de R.A. BRUCE. Les résultats respectifs sont : coefficients de corrélation R = 0,435 pour nous et R = 0,403 pour BRUCE. Compte tenu de l'importance de notre échantillon, ces corrélations sont hautement significatives : respectivement : $p < 0,0000001$ et $p < 0,0000001$.

Dans une <u>seconde étude</u>, nous avons observé l'effet de l'entrainement physique régulier sur les résultats de la spiroergométrie sur tapis roulant (17). Nous avons en effet constaté que chez les pilotes F-16, physiquement les moins entraînés les deux paramètres principaux de la spiroergométrie définissant le mieux, l'aptitude cardio-respiratoire, à savoir le $\dot{V}O_2MAX$ $mlkg^{-1}min^{-1}$ et la pente d'accroissement de la $\dot{V}O_2$ $mlkg^{-1}min^{-2}$, étaient nettement inférieurs à ceux relevés chez les pilotes F-16 bien entraînés.
Dans le but de démontrer l'effet favorable de l'entrainement physique, un groupe de 20 pilotes F-16 non entraînés a été étudié de manière plus approfondie (6). Ce groupe , qui, lors du premier test, avait enregistré des résultats médiocres de spiroergométrie, a été invité à suivre un entrainement physique pendant au moins six mois. Après cette période, ces pilotes ont été soumis à un second test de spiroergométrie sur tapis roulant. Des différences significatives ont été observées entre les résultats du premier et du second test et sont consignées dans les Tableaux IV et V et la figure 1. (7).

SPIROERGOMETRIE CHEZ LES PILOTES F-16 (BAF) : N = 20	$\dot{V}O_2$MAX $mlkg^{-1}min^{-1}$			PENTE $\dot{V}O_2$ $mlkg^{-1}min^{-2}$		
	OBSERV	PRED	ECART en DSR	OBSERV	PRED	ECART en DSR
Avant entrainement	43,32	49,64	-0,96	2,138	2,48	-0,83
Après entrainement	46,52	49,01	-0,343	2,433	2,436	-0,011
Différences en DSR	$\dot{V}O_2$MAX : + 0,637			PENTE $\dot{V}O_2$ + 0,82		

TABLEAU IV : DIFFERENCES EN DSR ENTRE LES MOYENNES DES ECARTS CONSTATES ENTRE LES VALEURS OBSERVEES ET PREDITES DES PARAMETRES SPIROERGOMETRIQUES AVANT ET APRES ENTRAINEMENT.

SPIROERGOMETRIE CHEZ LES PILOTES F-16(BAF) : N = 20	$\bar{X}$ AVANT ENTRAINEMENT	$\bar{X}$ APRES ENTRAINEMENT	TEST STATISTIQUE "t"	DEGRE DE SIGNIFICATION : p
$\dot{V}O_2$MAX OBS $lmin^{-1}$	3,283	3,57	2,058	0,05 *
$\dot{V}O_2$MAX OBS $mlkg^{-1}min^{-1}$	43,32	46,82	1,944	0,05 *
PENTE $\dot{V}O_2$ $mlkg^{-1}min^{-2}$	2,138	2,433	3,457	0,005 ***
$\dot{V}E$ ou R/V en $lmin^{-1}$	108,35	113,03	0,8	0,5 NS
RE	33,11	31,89	-0,77	0,5 NS
TEMPS MAX en min	14,4	15,4	1,592	0,2 NS
CHARGE en watts	300,5	312,4	0,85	0,5 NS
RENDEMENT en %	26	24,9	-	- ?
FC ou pouls	181,2	182,3	0,353	0,9 NS
POULS d'O_2 en ml	20,37	19,83	1,529	0,2 NS

TABLEAU V : COMPARAISON ENTRE LES MOYENNES ($\bar{X}$) DE DIX PARAMETRES PHYSIOLOGIQUES ET SPIROERGOMETRIQUES AVANT ET APRES ENTRAINEMENT CHEZ 20 PILOTES F-16 (BAF).

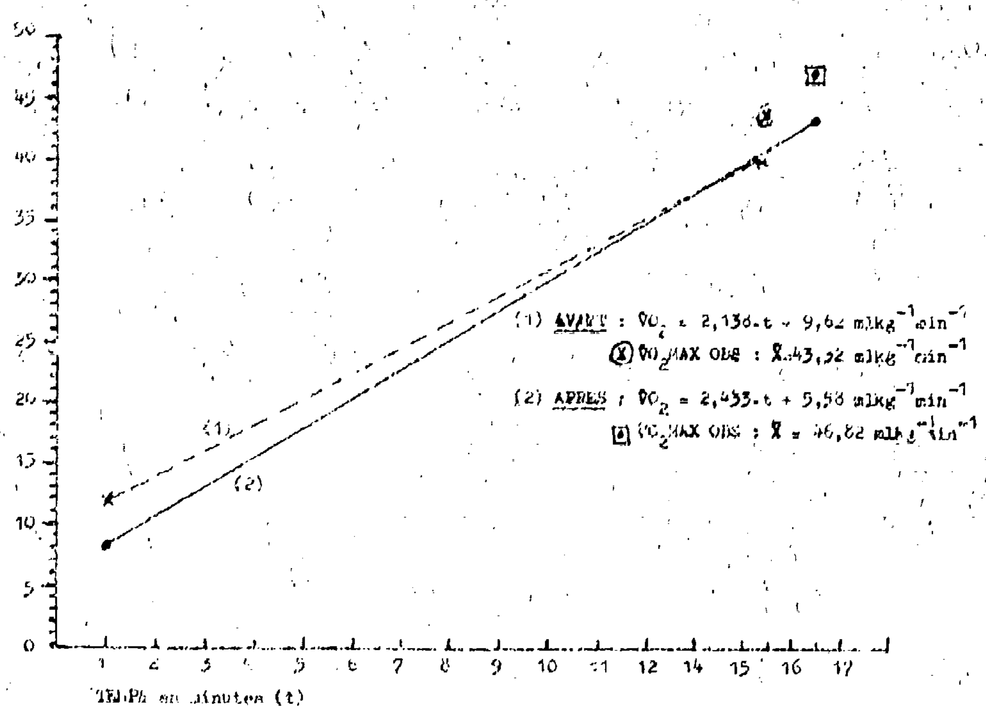

FIGURE 1 : $\dot{V}O_2$MAX ET PENTE DE LA $\dot{V}O_2$ AVANT (ligne pointillée) et APRES (ligne continue) ENTRAINEMENT PHYSIQUE CHEZ DES PILOTES F-16 DE LA BAF (N = 20).

Le Tableau IV indique les différences, exprimées en DSR, entre les moyennes des écarts constatés entre les valeurs observées et prédites des paramètres $\dot{V}O_2MAX$ $mlkg^{-1}min^{-1}$ et pente de la $\dot{V}O_2$ $mlkg^{-1}min^{-2}$ avant (1er test) et après entrainement (2ème test). Les valeurs prédites des paramètres spiroergométriques ont été calculées à l'aide des formules de prédiction (a) et (b). Le simple comparaison des valeurs observées dans le Tableau IV montre un accroissement de 8 % pour la $\dot{V}O_2MAX$ kg^{-1} et de 13,8 % pour la pente de la $\dot{V}O_2$.

Des équations de régression de la $\dot{V}O_2$ en fonction du temps t suivant le modèle $\dot{V}O_2 = a.t^2 + b$ et incorporant les valeurs moyennes de coéfficient de pente a et d'ordonnée à l'origine ou intercept b ont été établies avant (1er test) et après entrainement (2ème test) : voir le graphique de la figure 1. L'influence positive de l'entrainement physique sur les principaux paramètres de la spiroergométrie est ici bien illustrée.

Le Tableau V est une comparaison, avant et après entrainement, d'une dizaine de paramètres physiques et physiologiques susceptibles de s'améliorer avec l'exercice (2). La comparaison des moyennes de ces paramètres, avant et après entrainement, par le test statistique "t" et sa Table permet d'établir un triage parmi ces paramètres et de recommander les plus significatifs soit : la $\dot{V}O_2MAX$ observée en $lmin^{-1}$ et $mlkg^{-1}min^{-1}$. (* ou $p < 0,05$) et la pente de la $\dot{V}O_2$ $mlkg^{-1}min^{-2}$ (*** ou $p < 0,001$).

CONCLUSION

Lorsque l'on dispose de l'équipement approprié et que le groupe de sujets à examiner n'est pas trop important le test spiroergométrique d'effort maximal sur tapis roulant demeure la méthode de choix.
Les deux paramètres importants pour évaluer l'aptitude cardio-respiratoire sont la $\dot{V}O_2MAX$ $mlkg^{-1}min^{-1}$ et la pente d'accroissement de la $\dot{V}O_2$ $mlkg^{-1}min^{-2}$.
Nous avons observé une bonne concordance entre nos résultats de la $\dot{V}O_2MAX$ selon le protocole de Bruce et les autres tests similaires (Tableau II).

Dans une étude complémentaire, nous avons observé que l'entrainement physique régulier a amélioré les résultats du test spiroergométrique sur tapis roulant d'un groupe de vingt pilotes F-16 non entrainés au départ. Cette amélioration peut être due à un accroissement de la capacité aérobique dans les muscles, résultant d'une augmentation de la perfusion sanguine avec une plus grande différence artério-veineuse en oxygène, et à un débit cardiaque accru. (8)

Le test spiroergométrique sur tapis roulant, qui détermine avec une bonne précision le pouvoir aérobique, permet en outre : chez les sujets à pouvoir aérobique médiocre ($< \bar{X} - 1$ DSR) d'améliorer le degré d'entrainement physique et chez les sujets à pouvoir aérobique exceptionnel ($> \bar{X} + 1$ DSR) de restreindre leur entrainement physique surtout aérobique. En effet, chez ces derniers, des études récentes (14) ont montré que les sujets hyperentrainés ont un risque accru de perte de connaissance lorsqu'ils sont soumis à des accélérations fortes et prolongées en centrifugeuses.

Vu l'enregistrement électrocardioscopique continu, ce test nous permet en outre de suivre et de déceler des troubles du rythme ainsi que des altérations du segment ST qui pourraient démontrer une maladie coronarienne latente.

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RELATIONSHIP OF CARDIOPULMONARY FITNESS TO FLIGHT PERFORMANCE IN TACTICAL AVIATION

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SUMMARY

This paper describes current endeavors to identify whether cardiopulmonary fitness can positively influence flight performance in a tactical fighter community. Population analyses of experienced and student Naval aviators present evidence that the U. S. Naval aviation pilot community is in an above average state of physical fitness with less than average coronary heart disease potential. Correlations found in this study between cardiopulmonary fitness and psychophysiological responses that occur during simulated and/or actual flight operations present strong evidence that flight performance could be favorably affected.

INTRODUCTION

Numerous studies have shown a direct relationship of cardiopulmonary (aerobic) fitness to work performance (1). One with good cardiopulmonary fitness uses a lower percent of his aerobic power for any given workload. Cardiopulmonary fitness has also been shown to improve cardiovascular function, reduce overall physical/mental fatigue, and enhance cognitive function (2, 3, 4, 5). Additionally, the onset of cardiovascular disease seems to be less in a population of physically fit individuals. The incidence of coronary heart disease (CHD) and its impact on the U. S. Navy and Naval Aviation is a growing concern (6, 7). Discussion of risk factors such as hypertension, body fat, smoking, cholesterol levels, and lack of exercise are ever increasing in the literature. Sudden incapacitation due to cardiopulmonary disorder is a serious, but rare, event among aviators. Cardiopulmonary disease, however, to include coronary disease, hypertension, arrhythmias, and chronic obstructive/restrictive diseases produces a significant loss of highly skilled and expensive aviators usually at the mid-point of their flying career (8, 9).

Two concerns have now been presented: (1) What is the cardiopulmonary makeup of the young incoming aviators currently being trained who in the future will be flying our Navy high performance aircraft (HPA)? How do they relate to the general population? (2) What is the cardiopulmonary makeup of our experienced, yet older, aviators presently flying HPA in the fleet? How do they compare to the incoming students?

Assessing cardiopulmonary capacity or fitness in a clinical/laboratory setting is not new. Assessing, however, any relationship of aerobic fitness to flight performance in aircrew flying simulated or actual HPA exposed to frequent and repeated environmental/operational tasks (such as excessive $\pm$ G loading, high pulmonary demands, disorientation, extreme visual tracking requirements, multiple cognitive function demands, etc.), is not well known. It has been known for years that various operational exposures, especially acceleration and disorientation, may affect some physiological responses (10, 11). Monitoring of these physiological responses, principally, heart rate, temperature, and muscle tension during flight have also been common place for years (12, 13, 14, 15). What is not common place or common knowledge and is the purpose of this study; is to determine whether cardiopulmonary fitness (aerobic fitness) has any influence on those physiological responses and what that may mean in regards to flight performance (simulated or actual) in naval aviation fighter communities.

METHODS

To date, 111 male student and designated Naval aviators in the age range of 21-40 have been evaluated. Eighty-four of the subjects were student Naval aviators going through various stages of training at the Naval Air Station, Pensacola, Florida. Twenty-seven were HPA designated Naval aviators assigned to fighter aircraft squadrons Naval Air Station Oceana, Virginia. Test protocols were devised to assess cardiopulmonary efficiency in both laboratory and field (squadron spaces) environments. The test batteries consisted of: (a) pulmonary function testing to assess lung capacity and rule out obstructive/restrictive disease, (b) cardiovascular, pulmonary, and metabolic response during maximum treadmill exercise (Bruce protocol) to assess aerobic fitness, (c) blood chemistries pre- and post-exercise to assess coronary risk factors, and (d) body composition to assess any relationship between percent body fat and work performance.

Following comparison analyses between groups, correlation analyses were conducted between cardiopulmonary fitness and additional psychophysiological variables identified to be significantly associated with flight performance:

Comparison of Cardiopulmonary Fitness and Motion Sickness Susceptibility: Twenty-nine student Naval aviators participated as subjects. Motion sickness susceptibility was determined by using a Stille-Werner Rotator during a modified Brief Vestibular Disorientation Test (16). The test consisted of a constant clockwise rotation at 18 rpm with eyes closed and head tilts against the direction of rotation every 30 seconds for a total of ten minutes or until the subject requested to abort due to symptoms of motion sickness. Spin time, heart rate, respiratory rate, and skin temperature responses were then analyzed in relation to levels of cardiopulmonary fitness.

Comparison of Cardiopulmonary Fitness and Visual Acuity: Thirty-four student Naval aviators were used as subjects. An automated vision test battery was used to assess central and peripheral (static) acuity and peripheral movement detection. A Dynamic Visual Acuity testing device designed by Burg in the 1960s (17) and modified with Landolt C targets was used to assess decrement in visual acuity with increasing targets movement velocities. Analysis of relationship with cardiopulmonary fitness were conducted with emphasis placed on those dynamic visual envelopes determined to be present during operational flight, i.e., 20°/sec, 50°/sec, and 110°/sec.

Comparison of Cardiopulmonary Fitness and Heart Rate Response During Air Combat Maneuvers (ACM) Training Flights: Eleven highly experienced Naval aviators flying 23 ACM training flights on a Tactical Air Combat Training System (TACTS) Range were used as subjects. Each aviator was a member of an Adversary squadron designated to fly ACM on the TACTS range during training of fleet squadrons. Aircraft flown were the A-4, F-5, and the T-38. The training flights monitored in this study were classified as high speed with low to moderate G loading. Using a three lead electrocardiogram, heart rate response was collected with an in-flight solid state recording device ("Vitalog") every 2.5 seconds from pre-flight to post-flight. G loading for each ACM event (fight) was continuously monitored and recorded using TACTS. Correlations and differences of heart rate response were assessed for: pre-flight (includes time for dress and walk to the aircraft), take off, transit, ACM, landing, and post-flight (includes return to squadron spaces and removing flight gear).

RESULTS AND DISCUSSION

Mean exercise histories, Naval physical fitness test results, treadmill duration, and recovery time (Table 1) placed the student Naval aviator population in the "outstanding" category of overall fitness. Metabolic efficiency during progressive absolute working including max oxygen uptake (Vo_2 max), relative aerobic capacity per absolute work ratio, anaerobic threshold, and functional aerobic impairment (FAI) (18) demonstrated an above average group based on other population studies. Pulmonary function revealed average efficiency and lack of any obstructive or restrictive disease. Body composition, including grip strength, revealed average strength, yet lower than national average percent body fat (19). Coronary risk factors utilizing the USAF Coronary Artery Risk Evaluation (CARE)* (20) demonstrated a relative risk of 1.4 times for developing coronary heart disease as compared to a population of equal age with baseline values. This value is substantially less than that found in the general population with a relative risk of 3.0.

For a population close to 10 years older, the designated aviator group was not drastically different in overall fitness from the student aviators. Mean exercise histories, Naval physical fitness test results, metabolic efficiency, treadmill duration, and recovery time placed the designated Naval aviator population in the "good to excellent" category of overall fitness. The most prominent differences were found in coronary risk factors (principally smoking history and age) which expressed evidence of a greater trend toward future coronary heart disease. The Coronary Risk Factor (CRF) of the designated aviators of this study could not be determined due to the blood samples being destroyed in transit to the main laboratory.

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*CARE assesses the risk factors of age, smoking history, systolic blood pressure, and total cholesterol in comparison to a similar population with no risk factors. Any number greater than 1.0 represents a degree of risk which potentially could be reduced.

Motion Sickness Susceptibility.

Results of the BVDT demonstrated that there is an inverse relationship between spin abort time and cardiopulmonary fitness, $r = -.506$, $p < 0.01$ (Figure 1). Analysis of heart rate, respiratory rate, and skin temperature differences, however, revealed limited differences. Motion sickness symptoms, i.e., nausea, pallor, sweating, and sometimes vomiting are associated with impulses arising within the chemoreceptor trigger zone (CTZ) of the brain and by indirect stimulation (stomach) (11, 21). If a physiological basis is to be identified as causative factor for these findings vagal tone enhancement might be a likely candidate. It is well accepted that aerobic fitness training enhances vagal tone. The sensitivity, however, we are seeing in cardiopulmonary fit subjects may be due rather to neurophysiological conditioning than cardiopulmonary fitness. During the course of physical fitness training, an individual is conditioned to expect certain relationships among motion sensory inputs: vestibular, vision, proprioceptive. The sudden unexpected change in these relationships would thereby accent motion sickness impulses. Experience seems to allow for motion sickness desensitization; however, very susceptible subjects may not be able to progress far enough in their training program to acquire that necessary experience. If neurophysiological conditioning through fitness training is a causative agent, the simplest approach may be a desensitization program directed at learning new motion patterns, i.e., new sensory association patterns to successfully prepare or return susceptible crewmen to flight without motion sickness.

Visual Acuity.

Statistical review of the relationships of cardiopulmonary fitness with static visual acuity parameters did not reveal any significant correlations in the student Naval aviator age range population. Mean Dynamic Visual Acuity threshold values (minutes of arc) increased from 1.69 ± 2.50 at 20°/sec to 3.94 ± 1.80 at 110°/sec representing an equivalent visual acuity of 20/30 - 20/80. Dynamic Visual Acuity at angular velocity of 20°/sec was not found to be correlated with fitness; however, dynamic visual acuity at 50°/sec and 110°/sec expressed a cardiopulmonary fitness influence ($r = -0.40$ and -0.58 respectively, $p < 0.01$) (Figure 2).

Visual acuity has been shown to deteriorate as the angular velocity of an object increases (22). The variation in ability to discriminate detail in moving objects initially seems of little concern except, in the conditions of high speed, low level flight, air-to-air combat, and potential mid-air collisions. Practice on dynamic visual acuity at higher angular velocities has shown substantial improvement (23). Considering that cardiopulmonary fitness may also influence dynamic visual acuity enhancement certainly warrants further study in this area.

Heart Rate Response During Air Combat Maneuvers (ACM) training flights.

Many reports of heart rate increases during take off, flight, and landing have been found in the literature that date back as early as the 1930s when heart rate, systolic blood pressure, and respiratory rate data were collected on aviators during aerial acrobatics (12). Table 2 and Figure 3 describe similar heart rate increases of the designated naval aviators of this study during monitored ACM training flights. As a population, heart rate was found to significantly increase from starting heart rate*, during pre-flight, take off, transit flight, ACM, landing, and post-flight ($P < 0.05$). Each flight usually had two ACM events while on the TACTS range. The mean G loading during these events never exceeded 2.0 G. A heart rate lag was usually seen following the G loading, which was found to be correlated with mean G. This lag was most significant ($P < 0.01$) the first 60 seconds following each ACM flight. A sympathetic response to increase vascular tone to maintain cerebral blood flow following the rapid G onset is most likely the causative agent. Centrifuge studies have identified similar findings (24).

Smith, in his study of heart rate response during takeoffs and landings (25) observed that heart rate response appeared to be similar in magnitude. These results prompted the conclusion that "for the same amount of stress, the percentage increase in heart rate is independent of subject variability." In our study, flight experience was common and type of ACM flights and environmental conditions were similar. Therefore, we could assume a similar amount of stress was present. We found, however, that the amount of heart rate response was extremely variable among the aviators in all phases of flight. We also identified a physiological variable that was different among the group and that it appeared to be producing a significant influence on the heart rate response. The variable identified was cardiopulmonary fitness as defined by maximum oxygen uptake ($\dot{V}O_2$ max). We found that heart rate response was inversely correlated with cardiopulmonary fitness (Figure 4). This was true for pre-flight; $r = -.595$, take off; $r = -.616$, transit to the ACM range; $r = -.601$, ACM; $r = -.565$, return transit to base; $r = -.604$, landing; $r = -.559$, and post flight; $r = -.601$ (all $P < 0.05$). The amount of heart rate lag response to ACM though, was not found to be correlated with cardiopulmonary fitness.

*Starting heart rate is defined as the heart rate at time of activation of the monitoring device during flight gear doning.

It is difficult to determine whether a relationship between heart rate response and cardiopulmonary fitness means anything in regards to aircraft performance. In other words, can we say that an increase in cardiopulmonary fitness will help an aviator fly better? Some investigators question whether cardiopulmonary fitness is of any significance at all to actual flight of the aircraft. Heart rate response in flight has often been used as an index of both physical workload and mental stress (26, 27, 28). If we were to ignore mental stress we could feasibly compare heart rate response during each phase of flight with a similar heart rate response occurring during treadmill stress testing (1). The purpose would be to convert the recorded heart rate into corresponding estimated oxygen uptake thereby allowing prediction of the relative aerobic work (energy cost) of performing the absolute (physical) work occurring during flight. Attempting this approach in our study, however, we were unable to demonstrate the same relation with cardiopulmonary fitness as we did with just the recorded heart rate. This would suggest then, that the "mental" component of the workload would have at least an equal if not greater weight than the physical component in producing the significant relationship found between heart rate response and cardiopulmonary fitness. If enhanced performance capability in flight is demonstrated, it may be actually a sense of well being or self confidence derived from individual fitness. It is interesting to note that self confidence and/or well being have been identified as prominent results of fitness training and have shown to be positive factors in enhanced work productivity (2).

Unfortunately, we have not been able to select a means of accurately rating pilot performance for each flight of the experienced aviators in this study. In view of their data stress test, exercise history, family history of coronary disease, and heart rate responses in flight), however, it is hypothesized that their overall productivity (flight as well as non-flight) would show a positive relationship with their cardiopulmonary fitness.

CONCLUSION

It is apparent from the results acquired in this study that the fitness profile (cardiopulmonary and coronary risk) of our incoming student Naval aviators is of high caliber. Although maintenance of a similar level of fitness is somewhat less in the designated aviators 10 years older, the importance and consistency of maintaining a "good" fitness level appears to still be present.

Comparison analyses of cardiopulmonary fitness with other psychophysiological responses during simulated and actual flight present a strong evidence of a favorable cardiopulmonary fitness influence. This influence would thereby also suggest enhanced performance during flight. Expansion of this project has now resulted in the following additional analyses of the relationship of cardiopulmonary fitness to flight performance in tactical aviation: (1) a comparison analysis of cardiopulmonary fitness and cognitive function is being conducted using student Naval aviators as subjects. Each subject, after having their cardiopulmonary fitness identified take a variety of psychomotor tests including: comprehension, analytical tasking, target identification, short term memory, and reaction time analyses. (2) additional field studies are being conducted that include in-flight physiological monitoring of HPA pilots during carrier launch, recovery, and multiple flight operations, and (3) G-tolerance of those HPA pilots evaluated for cardiopulmonary fitness will be identified by centrifuge testing.

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TABLE 1. POPULATION COMPARISONS

	Student Naval Aviators	Designated Naval Aviators	GENERAL POPULATION
Resting Heart Rate (BPM)	63.3 ± 11.5	63.5 ± 11.7	72.0 (21)
Resting Blood Pressure (mm Hg)	119.1 ± 9.9 / 76.1 ± 7.7	121.1 ± 9.3 / 73.4 ± 5.7	120/80 (21)
AGE (Years)	23.9 ± 5.6	31.7 ± 3.6	20 - 44 (31)
HEIGHT (cm)	179.9 ± 6.9	181.7 ± 6.5	176.8 (31)
WEIGHT (kg)	77.7 ± 8.5	81.2 ± 9.1	78.6 (31)
BODY FAT (%)	12.0 ± 4.7	12.8 ± 4.4	15.0 (19)
*EXERCISE HISTORY	73%	54%	NOT AVAILABLE
CORONARY HEART DISEASE (CHD) HISTORY	0.2%	11%	NOT AVAILABLE
GRIP STRENGTH (kg)	50.7 ± 6.8	53.1 ± 7.8	49.0 (31)
SMOKING HISTORY	0.08%	16%	35% (34)
FVC (L)	5.9 ± 0.8	6.0 ± 1.0	5.57 (29)
FEV_1 (L)	4.7 ± 0.6	4.5 ± 0.7	4.49 (29)
FEV (25-75) (L/SEC)	4.8 ± 1.1	4.5 ± 1.[illegible]	4.87 (29)
TOTAL CHOLESTEROL (mg/dl)	180.9 ± 48.9	NOT AVAILABLE	220 (34)
HDL CHOLESTEROL (mg/dl)	48.8 ± 11.8	NOT AVAILABLE	44.0 (30)
TC/HDL RATIO	4.0 ± 1.4	NOT AVAILABLE	5.0
TRIGLYCERIDES (mg/dl)	81.2 ± 38.0	NOT AVAILABLE	104.0 (30)
CORONARY RISK FACTOR (CRF)	1.4 ± 1.2	NOT AVAILABLE	3.0 (20)
1.5 MILE RUN (MIN)	9.5 ± 1.0	10.2 ± 1.2	11.0 (32)
SITUPS	76.5 ± 13.6	75.0 ± 23.6	NOT AVAILABLE
SIT AND REACH (IN.)	4.6 ± 2.5	2.5 ± 1.1	NOT AVAILABLE
$\dot{V}o_2$ MAX ($ml \cdot kg^{-1} \cdot min^{-1}$)	53.7 ± 6.5	48.7 ± 7.4	45.4 (18)
TREADMILL TIME (MIN)	15.9 ± 1.7	14.6 ± 1.4	11.8 (18)
ANAEROBIC THRESHOLD (%)	61.7 ± 9.8	62.7 ± 5.8	NOT AVAILABLE
RECOVERY TIME (MIN)	30.3 ± 12.9	32.2 ± 13.3	NOT AVAILABLE
**RELATIVE AEROBIC CAPACITY	0.65 ± 0.7	0.77 ± 0.08	NOT AVAILABLE
***FUNCTIONAL AEROBIC IMPAIRMENT (FAI) (%)	8.0 ± 7.7	7.1 ± 9.5	NOT AVAILABLE

*Exercise history described as routine exercise 2-3 times per week for 20 - 30 minutes each.

**Relative Aerobic Capacity is the percent of maximal oxygen uptake ($\dot{V}o_2$ max) utilized at Stage 4 of the treadmill stress test.

***Functional Aerobic Impairment (FAI) is defined as the percent deviation between the observed and predicted values for $\dot{V}o_2$ max.

TABLE 2. MEAN HEART RATE AND FLIGHT PROFILE DURING AIR COMBAT MANEUVER TRAINING FLIGHTS

	START	PRE FLT	TAKE OFF	$TRANSIT_1$	ACM_1	ACM_2	$TRANSIT_2$	LAND	POST FLT
HR (BPM)	78.5 ± 9.5	94.9 ± 11.4	100.5 ± 26.2	91.1 ± 23.8	95.7 ± 20.5	99.3 ± 17.7	92.8 ± 20.5	106.2 ± 22.6	98.0 ± 15.8
TIME (MIN)		25.3	2.0	11.8	4.8	4.4	12.7	2.0	15.1
MAX + G_z					4.62 ± 1.3	4.78 ± 1.6			
MEAN + G_z					1.81 ± 0.4	1.98 ± 0.4			

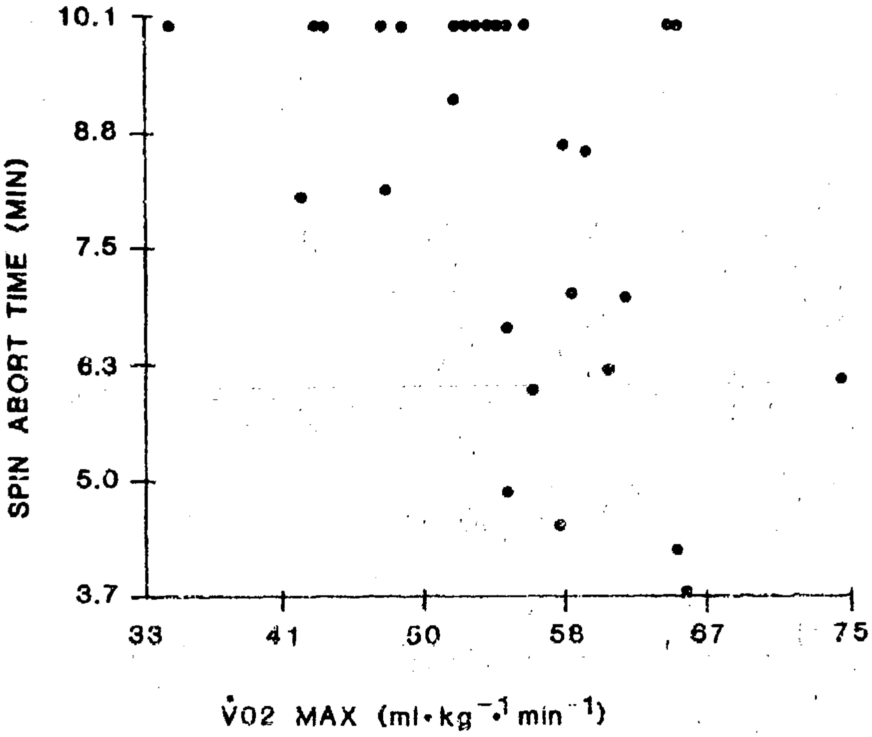

Figure 1. Correlation ($r = -0.56$, $p < 0.01$) of spin abort time (min) and cardiopulmonary fitness as measured by $\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)

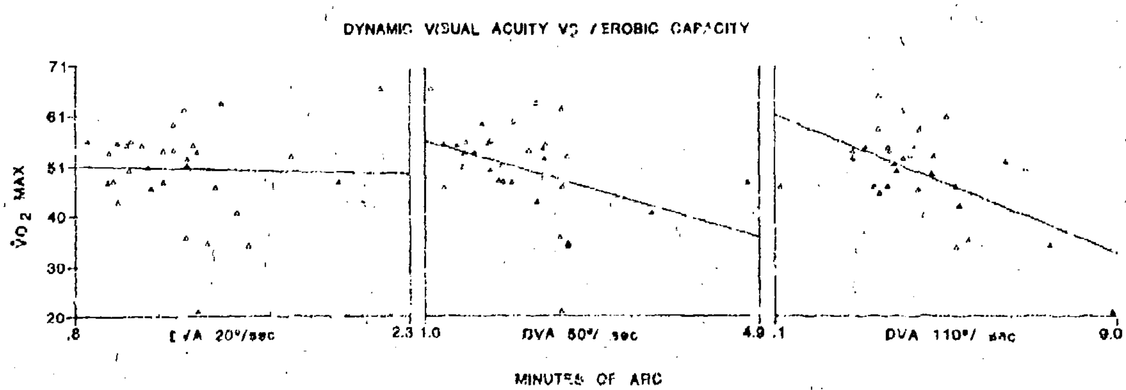

Figure 2. Correlations of cardiopulmonary fitness as measured by $\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$) and Dynamic Visual Acuity (minutes of arc) at 20°/sec ($r = -0.22$, $P > 0.05$), 50°/sec ($r = -0.40$, $P < 0.01$), and 110°/sec ($r = -0.58$, $P < 0.01$).

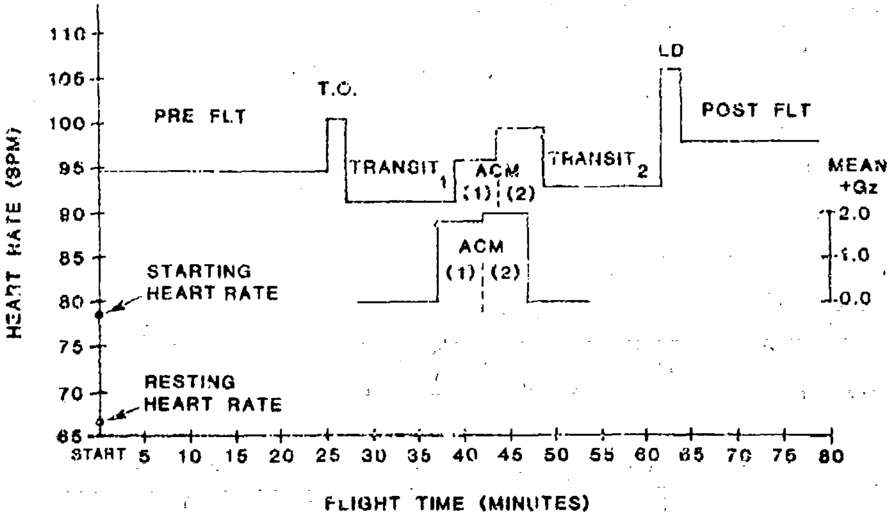

Figure 3. Mean Heart rate and + G_z response during Tactical Air Combat Training System (TACTS) Range ACM flights for 11 aviators during 23 flights. PRE FLT = preflight, T. O. = take off, Transit$_1$ = flight to TACTS range. ACM 1 & 2 = individual ACM events (fights), Transit$_2$ = return flight to base, LD = landing, Post FLT = post flight.

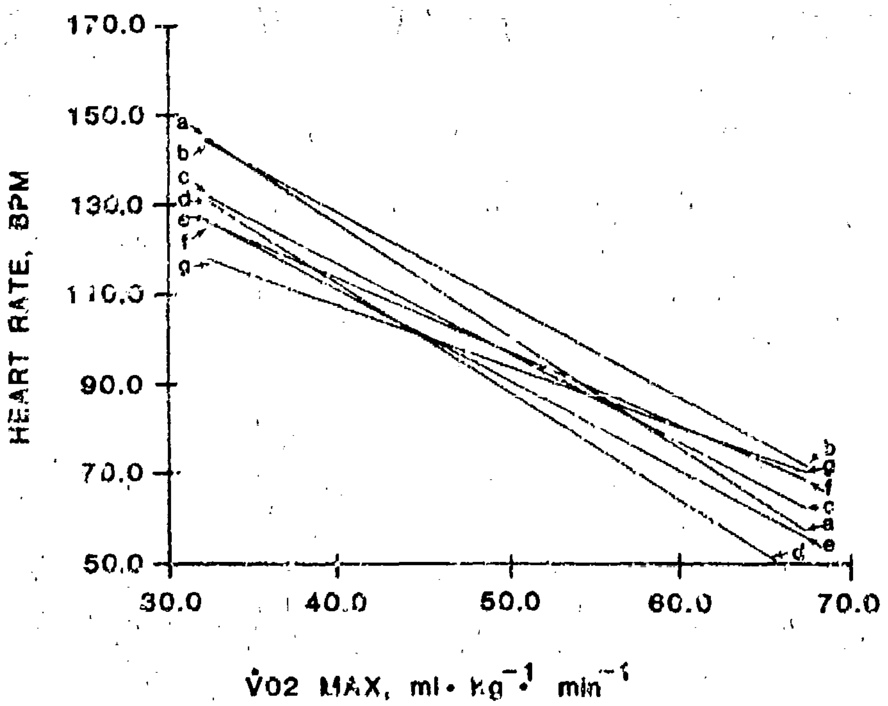

Figure 4. Best fit correlation lines for mean heart rate response during each flight phase and cardiopulmonary fitness ($\dot{V}o_2$ max) for 11 aviators during 23 ACM flights. a = take off, b = landing, c = ACM, d = TRANSIT$_1$ (flight to ACM range), e = TRANSIT$_2$ (return flight to base), f = post flight, g = pre flight.

DISCUSSION OF SESSION VI - MEDICAL SELECTION AND TRAINING: PHYSICAL FITNESS

(Papers 42, 43 and 44)

AIR CDRE ERNSTING (UK)

If I may, I would like to ask our Belgian colleagues about the increase in the slope of oxygen consumption against time on the treadmill. It appears to be due primarily to a reduction in the resting oxygen consumption of the subjects. Have you any comment to make on this observation?

AUTHOR'S REPLY (MÉD CDT PIRQUIN (BE))

Yes, as a matter of fact we have observed an increase of the slope for oxygen consumption but we also believe that one should not attach too much importance to the slope. In some subjects the initial values of oxygen consumption were somewhat higher than those of the other subjects due to hyperventilation. Thus these subjects started from a higher initial value, which gave a lower slope of oxygen consumption with exercise.

AIR CDRE ERNSTING (UK)

I would like to raise a point with Dr Grissett. Do you have any objective evidence that increasing physical fitness increases the susceptibility of aircrew to motion sickness other than the ground based experiments? There is no operational experience which suggests an increase in susceptibility?

AUTHOR'S REPLY (DR GRISSETT (US))

To the best of my knowledge that is correct.

HYPOBARIC TRAINING OF FLIGHT PERSONNEL WITHOUT COMPROMISING QUALITY OF LIFE

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SUMMARY

The increased incidence in decompression sickness during physiology training among U. S. Navy aircrew personnel and medical attendants requires a search for alternative means of permitting recognition and corrective action of hypoxia. The requirement for individual hypoxia training is considered valid not just by Navy regulations but by aeromedical practitioners throughout the world. A proposal is made to utilize a gas mixture consisting of 7.4% oxygen and 92.6% nitrogen to induce hypoxia at ground level. This would permit ground level hypoxia training with similar symptoms of hypoxia as presently demonstrated at 25,000 feet in a decompression chamber but would alleviate the primary cause of decompression sickness. All other U. S. Navy training objectives for the chamber exposure would be safely met and more efficiently demonstrated.

The initial financial burden in modifying the existing decompression training chambers would be moderate when considering development and manufacturing of a new training device.

The ultimate gain exists in decreased human suffering and the necessary return of credibility to the aeromedical training community. This is a must if we are to profess to "DO NO HARM."

HISTORY

The invention of the air pump by von Guericke in 1650 allowed the first simulation of altitude. A modified version of this pump was made for the renowned Robert Boyle for studying living things. Boyle's "The Spring of the Air," published in 1660 contains accounts of a multitude of studies on animals. Later in 1670, he described the now famous ". . . bubble moving to and fro in the waterish humour of one of its eyes," when he decompressed a viper in his "Exhausted Receiver" (1). No attempt seems to have been made to subject man to the "tortures" of the "exhausted receiver," although Boyle wrote of his ambition to have a chamber of appropriate dimensions.

One hundred and sixty-three years passed before man was the subject in an experiment using Boyle's copper sphere with an intermediate cylindrical section large enough for his subject (1). However, it took the genius of Paul Bert in 1874 to unravel the confused stories of balloonists and mountaineers to reveal the role of "oxygen therapy" in decompression to subatmospheric pressure.

It was in that same year, 1874, that Gaston Tissandier sought the advice of Paul Bert and together with his colleagues, Sivel and Crocé, experienced the effectiveness of oxygen in combating the disorder of altitude induced hypoxia (1,2). At the insistence of Paul Bert, the balloon was equipped with bags of oxygen (2). He had also trained the balloonists in the use of their crude oxygen equipment in his decompression chamber. Thus we have the first documented instance of aeromedical training of aircrew personnel prior to the initiation of an altitude exposure. Unfortunately, only one year after that training, on April 15, 1875, we also find documented the first two fatalities from acute altitude hypoxia. This occurred when this same threesome piloted the balloon Zenith to a terminal altitude of 28,820 feet and failed to utilize their precious oxygen until they had passed their useful conscious time (2).

Over two hundred and seventy years had passed from the experiments of von Guericke and Robert Boyle until, in 1941, the decompression chamber became an integral part of the aeromedical training program of flight personnel in the United States Navy. Today, the Navy maintains fourteen decompression chambers for the express purpose of aeromedical indoctrination and refresher training of candidates and designated aircrew personnel. The training objectives for the chamber are: (a) demonstrate and experience the objective and subjective symptoms of hypobaric hypoxia; (b) experience the effects of increased gas volume on the cavities of the body; (c) experience and demonstrate communicating and forced breathing against positive pressure; and (d) practice using personal and aircraft mounted oxygen and communication life support equipment.

The standard chamber training profile includes: (a) thirty minutes of denitrogenation for medical attendants; (b) ground level positive pressure breathing/communication demonstration by trainees; (c) ascent to 25,000 feet at 5,000 feet per minute; (d) one-half of students do hypoxia demonstrations and then the other half take their turn while no one remains off supplemental oxygen more than four minutes; (e) descent to 18,000 feet at 5,000 feet per minute; and (f) slow the descent from 18,000 feet to ground level at a rate of 2,500 feet per minute.

The first accumulation of data on the number of personnel trained in the chambers occurred in 1959 (3). Chamber training data has been collected from that time to the

present (with the exception of 1969, 1970, 1971, and from 1 January 1978 through 30 September 1978). Since January 1, 1959 until September 30, 1984, 445,879 trainees have experienced the decompression chamber. Each chamber flight requires that a minimum of two medical attendants (either physiologists or hospital corpsmen) remain inside to help alleviate dysbaric discomfort. Data showed 100,318 medical attendant exposures in the chambers over this same time period. The total exposures within the chambers for trainees and medical attendants were 546,197.

DECOMPRESSION SICKNESS

Disorders resulting from decompression chamber exposure are generally grouped into either trapped or evolved gas disorders. Trapped gas difficulties are minor in nature and are generally resolved by using techniques to equalize the pressures. Evolved gas disorders are potentially more injurious to health and range to certain forms that may result in death. The most recognized name for evolved gas disorders is decompression sickness or DCS. It is believed that DCS results from supersaturation of body tissues with nitrogen as ambient pressure decreases, a situation which leads to bubbles developing in the blood and tissues. This supersaturation is due to the relatively poor solubility of nitrogen in the blood so that the rate of decrease of the partial pressure of nitrogen in the tissues on ascent to altitude lags behind that of the ambient pressure (4). The U. S. Navy considers DCS as the most dangerous element of decompression chamber training. Accordingly, precautions have been established to eliminate or at least minimize the potential for DCS. Specifically: (a) denying chamber exposure to trainees who do not meet demanding medical screening requirements; (b) requiring thirty minutes of preoxygenation for the medical attendants to assist in denitrogenation; (c) requiring 100% oxygen usage throughout the chamber ascent and descent; (d) decreasing the terminal altitude achieved during any chamber profile; and (e) decreasing the maximum time permitted at the terminal altitude. Additionally, excessive physical exercise is discouraged prior to and after chamber exposure, and aircraft flights are not authorized for twelve hours post-decompression chamber training to an altitude in excess of 30,000 feet (5). However, these precautions have not eliminated nor significantly reduced the incidence of hypobaric induced DCS.

TABLE I. COMPARATIVE INCIDENCE OF DECOMPRESSION SICKNESS IN NAVY LOW PRESSURE CHAMBERS FROM 1 JANUARY 1959 TO 30 SEPTEMBER 1984

	Total Exposure	No. Cases of DCS	Incidence (%)
FURRY (1 JAN 59-31 DEC 68)			
Students	252,564	266	0.100
Inside Observers	60,000	35	0.060
Total	312,564	301	0.096
BASON (1 JAN 72-31 DEC 75)			
Students	65,736	20	0.030
Inside Observers	13,345	46	0.340
Total	79,081	66	0.078
FURR (1 JAN 76-31 DEC 77) (Unpublished)			
Students	31,645	10	0.030
Inside Observers	6,470	20	0.310
Total	38,115	30	0.078
BASON (1 OCT 78-30 SEP 81) (Unpublished)			
Students	47,380	39	0.082
Inside Observers	10,020	48	0.479
Total	57,400	87	0.152
HERRON (1 OCT 81-30 SEP 84) (Unpublished)			
Students	48,554	32	0.066
Inside Observers	10,483	30	0.285
Total	59,037	62	0.105
GRAND TOTAL	546,197	546	0.099

Investigations by Furry (3), Bason (6,8), and Furr (7) reported the incidence of DCS among chamber trainees and medical attendants. Their combined data tracks the number of DCS cases compared to the total number of chamber exposures from January 1, 1959 until September 30, 1981. This writer has collected the remaining data from October 1, 1981 through September 30, 1984, thereby making available similar data for a period of 22 years. All this data (Table I) was derived from the U. S. Navy Aerospace Physiological Training Quarterly Reports, NAVMEDFORM 6410/3 (9).

As previously stated, there were a total of 445,879 trainees exposed to altitude in Navy decompression chambers for this sample period of 22 years. A total of 367 trainees experienced some form of DCS during this period. This calculated incidence for the trainees is 0.08%. More simply stated, one trainee in every 1,215 developed the signs and symptoms of hypobaric induced DCS. With an average of 1,689 trainees per month being exposed to Navy chambers, approximately one DCS case per month results from our existing training procedures.

During the same time period, 100,298 chamber exposures were accumulated by the medical attendants, with 179 attendants having been subjected to hyperbaric chamber treatment to resolve the classic effects of DCS. Calculations show that DCS incidents of 0.18% have occurred in the medical attendant population. This has resulted in one attendant experiencing DCS out of every 560 who participate in chamber training.

The combination of trainees and medical attendants who have suffered from DCS results in 546 cases out of 546,197 exposures. An incidence of 0.099% occurs; i.e., approximately one hypobaric induced DCS out of every 1,000 people participating in decompression chamber training.

The statistics collected from the various investigators through the years 1959 to 1984, demonstrate a trend toward increased incidents of DCS. Furry's data (3) from 1959-1968 reported an overall incidence of DCS of .096%. Bason's research (6) from 1972-1975 showed an incidence of .078% while Furr's data (7) for the next two years, 1976-1977, showed the same incidence of .078%. However, Bason's second work (3) from 1978-1981 showed a marked increase in incidence of .15% with the major impact resulting within the medical attendant community. The remaining years from 1981-1984 show a continual rise in DCS over the years from 1959-1977, but a slight decrease over the three-year period from 1978-1981.

HYPOXIA TRAINING

The apparent increase in the incidence of DCS among medical attendants raises an inevitable question in the minds of the aerospace medical researchers. Is it really necessary to expose any member of the physiology training community or aircrew trainees to altitudes in excess of the normal operational flight altitudes, inasmuch as such ambient exposures are rare (8)? The incidence of DCS reported here suggests that present decompression chamber flight profiles are in need of reexamination, unless DCS is to be dismissed as either a necessary risk or a mere "quality of life" judgment. Bason (6) clearly reflected concern for the hazard of DCS when he reported "Altitude chamber flight profiles beyond minimum levels acceptable for teaching the effects of acute hypoxia cannot be defended as long as less dangerous avenues are available." The question to be answered is, "Is the risk of hypobaric induced DCS worth the training achieved by decompression chamber exposure to induce hypoxia?"

Other military armed forces are beginning to weigh the risk of decompression chamber training. As reported by Cramer (10), "Since 1965 the United States Air Force has treated 586 cases of DCS. Four hundred and sixty-seven were altitude induced and most occurred in training chamber situations." An exceptionally high ratio of United States Air Force DCS cases appear to be resulting from training scenarios. A five-year study ending in 1981 by Crowell (11), reported 69 cases of DCS occurred out of 21,423 training exposures (0.32%) for the Canadian Forces. These statistics would certainly drive doubt into the mind of the most liberal of chamber operators.

Making a correct diagnosis of DCS depends greatly on the history the patient presents; therefore, it is imperative that an accurate patient history be taken prior to training. Another reason to decrease the opportunity for altitude induced DCS is presented by Murphy (12) when he and his co-authors reported on several factitious cases of DCS. In one case at least a dozen hyperbaric physicians were involved by patient examination or phone consultation. All were fooled by a "classic presentation" of DCS. Due to the potential severity of DCS, the experienced physician will treat first and ask questions later. Harding and Mills (4) commenting on the predictability of DCS, report that "Finally, and as of yet unexplained, true individual susceptibility of DCS does seem to occur." However, consistent and repeatable prediction of susceptibility of DCS has not been defined by way of a clear-cut process whereby hypobaric training activities can employ this practice. Couple these universal statistics surrounding the increasing incidence of DCS with the apparent change in training philosophy as to the usage of the hypobaric chamber, an investigator must consider an alternative to demonstrating hypoxia to aircrew personnel without decreasing their quality of life.

DISCUSSION

Leaders in the aerospace physiology community contend that there is adequate justification to train aircrew to recognize and correct for hypobaric hypoxia. Harding and Mills (13) state that "The fall in total atmospheric pressure and the consequent reduction in the partial pressure of oxygen (PO_2) poses the greatest single threat to anyone who flies, hypoxia." The United States Air Force contends that training students to recognize their hypoxia symptoms is an important phase of the aerospace physiological training program.

Charles Lindbergh (14) once wrote that training to recognize and avoid hypoxia works. He stated that, "It saves lives."

Brooks (15) in reporting incidents occuring from loss of cabin pressurization, supported hypoxia training when he wrote, "There were three cases of hypoxia, in which the pilots recognized their symptoms and followed established procedures leading to an uneventful landing which may be attributed to effective aeromedical training."

Ernsting in May of 1984 (16), declared that "The most important single hazard of flight at high altitude is hypoxia." He continues, "All aircrew should receive initial and refresher training in the effects of hypoxia. It is highly desirable, and indeed in most Air Forces it is mandatory, that this training includes personal experience of hypoxia in a hypobaric chamber."

However, the serious nature of the threat of hypoxia and the probability of occurrence of this threat continue to be the pivot-point around which all other aerospace physiological disorders revolve. Ernsting (16) reminds us not to overlook the large individual variations in the effects of hypoxia and the modifying effects such as mode of exposure, rate of ascent, physical exercise, temperature, etc. Inducing hypoxia by way of decreasing barometric pressure results in a variety of changes in respiration, circulation, and blood chemistry that can't avoid masking or complicating the actual individual effects of hypobaric hypoxia. Harding and Mills (13) report that in moderate hypoxia, such as breathing air at 25,000 feet, cardiac output and heart rate are increased while the overall peripheral resistance is reduced. Rahn and Otis (17), comparing different altitudes, reported that the higher the altitude the greater is the ventilation, the larger is the initial rise in the alveolar respiratory quotient, and the lower does the alveolar PCO_2 fall. Bason (6) reports that changes in hemostatic systems have been discovered following decompression from both normobaric and hyperbaric environments in the absence of overt signs and symptoms of DCS. These alterations include loss of circulating platelets, increased serum fibrinogen, and an increase in certain serum enzymes.

We have reviewed the seriousness and life threatening dangers associated with DCS while confirming the requirement for individual experience with hypoxia. Accordingly, hypoxia demonstrations at a safe altitude such as ground level would appear to alleviate many of the major and minor maladies resulting from altitude induced hypoxia. Ground level training would alleviate the aerodontalgia, vasovagal syncope due to abdominal gas expansion, aerosinusitis, and barotitis media. Ground level training would neutralize the complications associated with Boyle's law, Henry's law, and Charles' law. The question may be asked as to the best way to train students in mechanically relieving the build up of trapped gas in the ears and sinuses. In response, the prevalence of ear blocks clusters into two communities: (a) those individuals with respiratory ailments who should have been medically screened and placed in a grounded status; and (b) those inexperienced individuals who have not mastered the technique of valsalva. Ground level training will permit valsalva practice in a controlled manner without the presence of pain resulting from a pressure differential between the middle ear and the chamber environment.

Now all that remains is to develop a means to safely induce ground level hypoxia to aircrew personnel which would allow for individual characteristics of hypoxia similar to those experienced in an actual aircraft hypoxic incident.

MIXED GASES

The actual composition of dry atmospheric air does not change from sea level to 70,000 feet. The air is composed of 20.94% oxygen, 79.02% nitrogen, .04% carbon dioxide, and a small percent of rare gases. Any decrease in the percent of inspired oxygen will result in some degree of hypoxia. The questions to be answered are, "What is the correct percent of oxygen to use and what should comprise the remaining gas?" Through personal communications, Dr. Christian Lambertsen reported inducing hypoxia to divers training with self-contained breathing systems in order to demonstrate the risk of improperly preparing the gases making up their air supply. A great deal of work has been done with mixed gases using pulmonary function and gas transportation systems. These usually dealt with 6% to 8% oxygen systems at ground level. West (18) carried out measurements of maximal exercise to throw light on the way in which the mountain climbers, Massner and Habeler, were able to reach the summit of Everest without supplementary oxygen. He used a bicycle ergometer at Camp II (20,700 feet) and gave the climbers inspired mixtures containing low oxygen concentrations. In this way, it was possible to measure maximal oxygen uptake with the inspired PO_2 of 43 mmHg which is the same as on the Everest summit (29,028 feet).

Most mixed gases research has involved oxygen and nitrogen. The impact on respiratory quotient, hyperventilation, and conflicting symptoms with hypoxia have steered researchers away from including carbon dioxide as one of the mixed gases. For those reasons, the mixed gases to be used to induce hypoxia at a safe altitude should be oxygen and nitrogen. What remains to be decided is the "quantity of each gas" to be utilized to satisfy the training objectives.

Much research has been accomplished to determine the partial pressure of oxygen at the alveoli at practically any given altitude. Since the Navy has a fixed requirement to demonstrate hypoxia to its aircrew personnel at an altitude of 25,000 feet, the logical conclusion would be to mix the gases in pressures that would impact the body as if it were at 25,000 feet. Most researchers agree with only slight variation as to the alveolar PO_2 at 25,000 feet. Harding and Mills (13) report that most physiological changes occur within three to five minutes of sudden exposure to an altitude of 25,000 feet by which time the alveolar PO_2 is 30 mmHg. This is consistent with the trend of decreasing alveolar PO_2 with increasing altitude. Rahn and Otis (17) report alveolar PO_2 to be 33.4 mmHg at 22,000 feet. West (18) reported an alveolar PO_2 of 35 mmHg at an altitude of 21,300 feet.

The resultant alveolar PO_2 at 25,000 feet is primarily dependent on the inspired PO_2 at that altitude. The gas equation (Figure 1) can be utilized to calculate the inspired oxygen in mmHg and/or percent of oxygen available at 25,000 feet. Once this factor is known, the same equation can be used to discover the ground level requirement in percent of oxygen that will provide the 25,000 feet equivalent in mmHg of oxygen. At 25,000 feet the barometric pressure is 282 mmHg. Subtracting the constant pressure for water vapor of 47 mmHg results in 235 mmHg of remaining gases. Multiplying the 235 mmHg by the percent of oxygen available at 25,000 feet, 20.94% will provide the mmHg of oxygen available in the inspired air at 25,000 feet. Accordingly, 49.21 mmHg of oxygen is available in the inspired air to each trainee during a 25,000 feet hypoxia demonstration.

FIGURE 1. GAS EQUATION SHOWING DETERMINATION OF GROUND LEVEL AND 25,000 FEET INSPIRED OXYGEN EQUIVALENCE

Ground Level	25,000 Feet
760 mmHg	282 mmHg
-47 mmHg H_2O	-47 mmHg H_2O
713 mmHg	235 mmHg
X.069 % of O_2	X.2094 % of O_2
49.20 mmHg of Inspired 02	49.21 mmHg of Inspired O_2

Using the same formula but using the ground level barometric pressure of 760 mmHg, one can calculate the percent of oxygen required to provide the same inspired partial pressure of oxygen at ground level that exists at 25,000 feet. This is 6.9% which translates into an inspired partial pressure of oxygen of 49.20 mmHg.

Presumably, if the inspired partial pressure of oxygen is equal at both altitudes, then the alveolar partial pressure of oxygen will be equal. Enough physiological equality will exist to result in similar experiences under hypoxic conditions.

However, the proposed ground level gas mixture contains an increase in nitrogen from 78.07% to 93.1%. In 1946, Fenn, Rahn, and Otis (19) reported that when there is an increase in partial pressure of nitrogen, then the alveolar partial pressure of oxygen will be affected. With an increase in nitrogen of 15.06% there is a change in partial pressure of oxygen of 2-3 mmHg. This is equivalent to a 0.5% requirement for modification to the delivered partial pressure of oxygen. Accordingly, it is expected that by increasing oxygen to approximately 7.4%, the resultant rise in alveolar PO_2 will bring about the equivalence sought after.

Another concern that must be noted when increasing inspired nitrogen is the potential for DCS. Additional precautions are not considered necessary for the prevention of DCS for environmental exposures as minor as proposed here. The proposed procedure for post-hypoxic exposure, that of switching to 100% oxygen and positive pressure breathing, will greatly assist in tissue denitrogenation. A possible advantage to ground level induced hypoxia followed by denitrogenation is that the physiological training sites will not be required to aeronautically ground the trainees for a specified period of time.

TRAINING EQUIPMENT

The existing Navy aircrew personnel training quotas dictate the time allotted for physiological training. Accordingly, mass hypoxia demonstrations will remain a time efficient necessity. After rather simple modifications, the existing decompression chambers can effectively and safely satisfy the proposed training procedure. All Navy chambers have primary and secondary oxygen systems. Completely isolating these systems is required. One system will continue to deliver 100% oxygen while the other system will deliver 7.4% oxygen and 92.6% nitrogen. The addition of a mixed gas delivery manifold

system will be required from the bottled source to each trainee console. A trainee console must be manufactured to resemble the face and operating mechanism of the oxygen regulator. This will provide operational realism yet allow the delivery to the trainee of either gas system at the discretion of the chamber operator. In this way, the same size training classes can be accommodated as presently exist at the physiological training sites. Additionally, due to the time saved by not preoxygenating and by not having to ascend and descend the chamber, training quotas could be increased, thus bringing greater efficiency to the training site and thereby returning the aircrew personnel back to their squadrons and into their aircraft more quickly.

RECOMMENDATIONS

A new training scenario is recommended to conduct hypoxia demonstrations on aircrew personnel in a manner that will satisfy training objectives while alleviating all potential for DCS. The scenario is as follows: (a) conduct a classroom presentation on aeromedical factors threatening to the aircrew personnel in flight; (b) provide a classroom briefing on chamber training, hypoxia demonstrations, and emergency procedures (e.g., fire, etc.); (c) enter decompression chamber and don communication helmet and oronasal mask delivering air at ground level pressure; (d) check trainees for ease of communicating and breathing; (e) chamber operator will initiate flow of mixed gases (7.4% oxygen and 92.6% nitrogen at ground level pressure) to one-half of the trainees and start the stopwatch for the hypoxic period; (f) one-half of the trainees will begin performing their preassigned, mission oriented hypoxia demonstrations; (g) when the trainees feel the signs and symptoms of hypoxia, they are instructed to turn their individual oxygen regulator from the normal (ambient) oxygen position to the 100% oxygen position; (h) by four minutes, medical attendants will ensure all trainees are switched to 100% oxygen and fully recovered from hypoxia symptoms; (i) the other half of the trainees now perform their hypoxia demonstrations exactly as performed by the first group; (j) trainees individually report their own symptoms of hypoxia; (k) chamber operator will instruct the trainees on breathing and communicating against positive pressure breathing; (l) under the watchful eye of the medical attendants, each trainee will demonstrate the valsalva technique to practice clearing the ears and sinuses; (m) trainees will remove helmets and oronasal mask and return to the classroom for a chamber training debrief and continue their training evolution.

The advantage in dividing the trainees' hypoxia demonstration into two groups is to permit objective as well as subjective symptoms to be viewed and experienced.

The trainees will denitrogenate for approximately six minutes during the recovery and hypoxia symptoms reporting periods. Ten minutes of additional denitrogenation will occur during the positive pressure breathing demonstration and valsalva practice session. The first group to demonstrate hypoxia will receive another four to five minutes of breathing 100% oxygen while the second group experiences hypoxia. Accordingly, trainees will denitrogenate from 16 to 21 minutes after their ground level hypoxia experience.

CONCLUSIONS

The increased incidence in decompression sickness during physiology training among U. S. Navy aircrew personnel and medical attendants requires a search for alternative means of permitting recognition and corrective action of hypoxia. The requirement for individual hypoxia training is considered valid not just by Navy regulations but by aeromedical practitioners throughout the world. A proposal is made to utilize a gas mixture consisting of 7.4% oxygen and 92.6% nitrogen to induce hypoxia at ground level. This would permit ground level hypoxia training with similar symptoms of hypoxia as presently demonstrated at 25,000 feet in a decompression chamber but would alleviate the primary cause of decompression sickness. All other U. S. Navy training objectives for the chamber exposure would be safely met and more efficiently demonstrated.

The initial financial burden in modifying the existing decompression training chambers would be moderate when considering development and manufacturing of a new training device.

The ultimate gain exists in decreased human suffering and the necessary return of credibility to the aeromedical training community. This is a must if we are to profess to "DO NO HARM."

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14. Abstract

The conference proceedings reviewed and made recommendations with respect to the medical selection and physiological and physical training of pilots who are to operate future fighter aircraft. The relevant characteristics of a proposed USAF fighter and the European Fighter Aircraft were discussed and used as the basis for the selection and training considerations. The contributors drew upon the experience of the medical selection of pilots for present fighter aircraft. The cardiovascular, vision and vertebral column aspects of medical selection and monitoring are considered in depth and recommendations made as to the methods which should be employed in the future. The influence of physical fitness upon pilot performance is addressed. The philosophy and practice of physiological training of aircrew is reviewed with emphasis on the value of the human centrifuge in teaching G protective manoeuvres.

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